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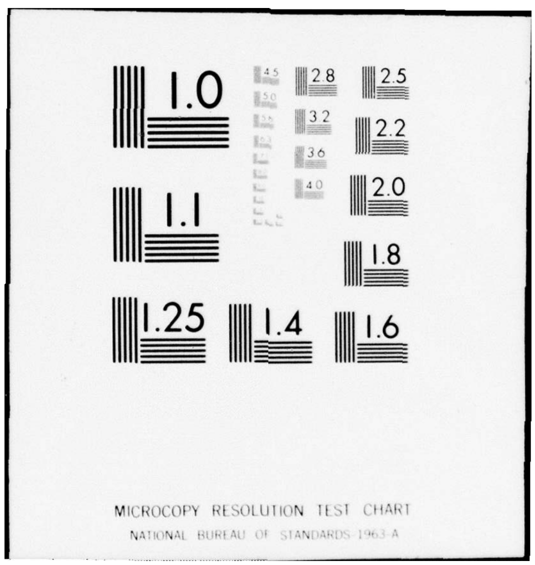
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TECHNICAL REPORT NO. 192

ANALYSIS OF GUNNER AIM ERRORS FROM THE TANK AGAINST HELICOPTER OPERATIONAL PERFORMANCE (TAHOP) EXPERIMENT

JULIAN A. CHERNICK
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JANUARY 1977

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Data from the TAHOP experiment are analyzed, principally to establish lead estimate errors and implementation errors suitable for calculating hit probabilities of tanks firing APDS rounds from their main guns at helicopters. Comprehensive investigations were carried out for a hovering helicopter, and to a somewhat lesser extent for a helicopter flying at constant speed on a level course. Less extensive analyses were made for the other helicopter maneuver conditions involved in the test. Detailed data for each firing event are described and sample tabulations provided.

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ANALYSIS OF GUNNER AIM ERRORS FROM THE TANK AGAINST HELICOPTER OPERATIONAL PERFORMANCE (TAHOP) EXPERIMENT

1. INTRODUCTION

This report presents an analysis of the Tank Against Helicopter Operational Performance (TAHOP) experiment. The TAHOP was conducted by the US Army Combat Developments Experimentation Command (CDEC) in August 1973 at Hunter-Liggett Military Reservation, California as a part of CDEC Experiment 43.8: Attack Helicopter/Daylight Offense. The objective was to generate quantitative data related to the aim errors of tank gunners engaging attack helicopters. The need for this information was identified in connection with a CDEC requirement for hit/kill probability estimates applicable to the T-62 tank main gun firing APDS rounds at such targets. The lack of information on gunner performance against a helicopter target constituted the principal gap in information required to make credible estimates of the capabilities of tanks to hit helicopters with main gun ammunition. The test data generated in TAHOP were transmitted by CDEC to US Army Materiel Systems Analysis Activity (AMSAA) for analysis. This report indicates the conditions of test, tabulates reduced data, and discusses what has been learned from analyses of the data.

The major part of the test, referred to subsequently in this report as the basic TAHOP, attempted to simulate the firing capabilities of the Soviet T-62 tank when the stadia range finder contained in the telescope is used for range estimation, and mental lead computations by the gunner are based on his estimate of target speed. Target acquisition was, by design, not addressed in the experiment. The US M60A1 was necessarily used in place of the Soviet T-62. There is no stadia range finder in the sight of the M60A1 and, therefore, a technique closely related to the stadia process was used for range estimation. The procedure associated with the "WORM" formula

Width (meters) Over Range (kilometers) = Mils

was used to determine the range. The planning documents (Appendix A and Reference 1) and partial reports on the test (References 2 and 3) contain much fundamental information about what was attempted and why. (The planning documents, however, are not necessarily a reliable source of information concerning what was actually done in the test.)

An addition to the test, referred to subsequently as the add-on TAHOP, was concerned with the gunner performance capability associated with two fire control systems which incorporate lead automatically. This addition to the test is felt to be more representative of the capabilities of state of the art systems. It provides otherwise non-existing data related to gunner performance for the M60A2, M60A3, and XM1 candidate tanks, as well as for possible more advanced Soviet systems. Further information concerning the objectives and design of the add-on portion is contained in a second letter from AMSAA to CDEC contained in this report as Appendix B.

Reference 2 is CDEC's final report on the TAHOP experiment. AMSAA SAO Interim Note No. 9 (Reference 3), which contained preliminary results of AMSAA's TAHOP data analyses, should be considered superseded by the present report.

2. TEST DESCRIPTION AND DATA COLLECTED

2.1 General.

This section gives a brief description of TAHOP and indicates the general nature of the test data obtained. Conditions that one needs to understand to follow the analyses and discussions of this report are emphasized. The Army AH-1G Cobra helicopter was used as the target throughout. Both the basic and add-on portions of the test were conducted simultaneously by locating all the tanks in the same general vicinity. Target flight path, range, presented area, and exposure time thus appeared about the same from any of the tank locations. Care was taken to ensure that tank turret movement and vision were not obstructed by the other tanks nearby. Multiple observers were used in rotation during the course of the experiment in order to obtain a more representative sampling of the gunner capabilities. The specific maneuvers performed by the helicopter varied in many respects from case to case, but were generally characterized by low altitude crossing or attacking profiles, with the horizon within five degrees of the target. Most flight durations were from 30 to 90 seconds. A maneuver classification scheme consistent with the design plan of the test was adopted for the analyses. The classification accounts for the following categories:

a. Hover.

b. Constant Speed Level.

c. Constant Speed Non-Level.

d. Constant Speed Level (Tanks canted).

e. Lateral (Side-to-side pendulum-type motion).

f. Nap of Earth.

g. Other Evasive Targets (Various accelerating paths).

2.2 Basic TAHOP.

Six M60A1 tanks were utilized in the basic portion of the test. The gunners viewed through the M105D telescopes (8X) and used the turret controls in the power mode. The M105D sight, depicted in Figure 2-1, is similar to the gunner's telescope (3.5X or 7X) with a built-in ballistic reticle that is part of the primary fire control of the T-62. The most prominent feature of this sight is a series of staggered horizontal

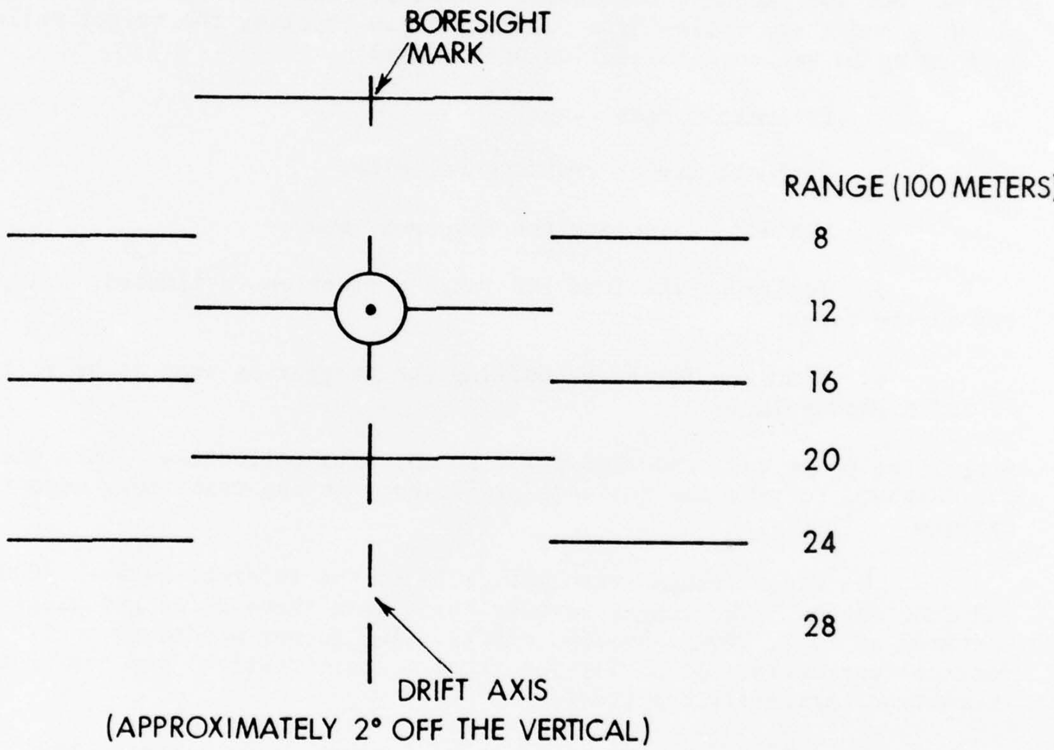

Figure 2-1. Gunner's Sight Picture.

lines that indicate the degree to which the gun must be superelevated in order to compensate for the fall of the round due to gravity. The spacing between the horizontal lines corresponds to the amount the round falls as a function of the indicated target ranges. The nearly vertical line in the center of the sight reticle determines the azimuthal location of the round in the gunner's frame of reference. The 2 1/4 degree tilt in the sight picture compensates for drift to the right due to interaction of gravity with the spin of the round.

The gunner's tasks were to slew the gun to the approximate target location, acquire the target somewhere near the edge of the sight picture, and then, following a command, begin tracking the target while performing in sequence the following subtasks:

a. Estimate target range.

b. Estimate target crossing velocity.

c. Mentally calculate the required lead.

d. Implement the lead and range corrections estimated, i.e., lay on the target.

e. Simulate firing by pulling the trigger as soon as he felt he had a good solution.

A training phase was conducted prior to any data collection. This phase was intended to give the subjects proficiency in the tasks they were to perform.

The target ranges were primarily in the interval between 1000 and 3000 meters. The ranges were selected from three major groupings centered at 1500, 2000, and 2500 meters. The gunner needed to apply vertical corrections primarily for range (superelevation) and horizontal corrections primarily for lead.

The velocity component of prime concern in determining lead requirements is the component of the total velocity in the plane perpendicular to the tank-to-helicopter line-of-sight. This velocity is referred to as the crossing velocity. Because the APDS round maintains a high velocity over the range interval tested, the proper lead correction does not greatly depend on the range; therefore, the correction rule of 1/3 mil per knot of crossing velocity that gunners were instructed to use to mentally calculate the required leads is a good approximation. The component of target velocity along the line-of-sight was a negligible contributing factor to the gunner aim errors, since the time of flight of the round is very short (about 2 seconds to the maximum target range tested).

2.3 Add-On TAHOP.

For the automatic lead systems, only one M60A1 tank was used. One gunner was used in this portion of the test. The gunner was instructed to simulate firing two rounds per run, one with no lead or superelevation, the other with only vertical lead, if required. In the system simulated by the first firing, the automatic lead system was assumed to be operating in both the horizontal and vertical directions (a two-axis lead system). In the system simulated by the second firing, the gunner was supposed to mentally estimate a vertical velocity and required vertical lead, while the sight would automatically provide any required horizontal lead and superelevation (a single axis lead system). An added requirement for the automatic lead systems was for the gunner to track the target for two seconds prior to firing to provide the lead computation system enough time to generate a valid solution.

2.4 Data Collected.

Data sources were as follows:

a. Survey of tank positions prior to the test runs.

b. 16mm color movie film.

c. CDEC M-33 radar system.

d. Gunner estimates recorded by test personnel.

The film was exposed at a nominal 16 frames/second; the cameras were mounted on the gun tube of each tank. The film shows the boresight panel location for each trial, followed by the gunner's tracking record of the helicopter target. In the margin of the film frame, the range timing signals and the tank trigger pulls were recorded. Film reading was accomplished by CDEC personnel. Where film could not be read, explanatory messages were provided within the data for that tank/trial combination.

The radar system also was configured to provide data at 1/16th second intervals. The helicopter position versus time was recorded on digital magnetic tapes. Tank firing indications were also recorded on the radar tapes.

The gunner's estimates of target range, crossing velocity, and intended lead corrections were recorded on cards during the experiment by a data taker who was located in the tank commander's position. The lead requirements were primarily in the horizontal plane. The gunners were instructed to estimate and apply lead in the direction of target motion. The test did not have instrumentation adequate to distinguish between gunners applying lead based on horizontal crossing velocity and gunners applying lead based on the combined horizontal and vertical crossing velocity.

3. DATA REDUCTION METHODOLOGY

3.1 General.

Reduction of data constituted a major task. This section discusses the procedures used for converting the test data provided by CDEC to forms more directly useful for various analyses. The objectives of data reduction efforts were to determine, for each test run:

a. Range and lead required at time of firing.

b. Gunner's ability to estimate range and lead requirements.

c. Gunner's ability to implement the range and lead adjustment he thought appropriate.

d. Gunner's overall capability to "lead and lay".

Figure 3-1 shows how the available data are related to these objectives.

3.2 Range and Lead Required.

Figure 3-2 indicates how range and lead requirements can be obtained from survey data and radar data. A smoothing technique was required to make the radar data useful for determining velocity. The technique used, which is discussed in Reference 4, involved the use of a third order Butterworth filter to attenuate frequencies higher than a so-called "cutoff" frequency. A cutoff frequency of about 0.1 cycle/second was used for the TAHOP data. Problems affecting the reliability of the data obtained are covered in Subsection 3.6.

3.3 Gunner's Range and Lead Estimation Errors.

By comparing the gunner's estimates of range and lead required to the actual range and lead requirements, one can determine the gunner's range estimation and lead estimation errors. Gunner range estimation errors were calculated by subtracting the actual value from the estimated value so that a positive estimation error corresponds to the gunner overestimating range; underestimates are represented by negative errors. Lead estimation errors were calculated in one of the following two ways:

a. For most analyses, they were determined like range estimation errors; thus, a positive error corresponds to an overestimate.

b. In some other instances, the need for compatibility with implementation errors led to the use of a sign convention whereby a positive lead estimate error implies an impact to the right of the target (for horizontal lead estimate errors) or above the target (for vertical lead estimate errors).

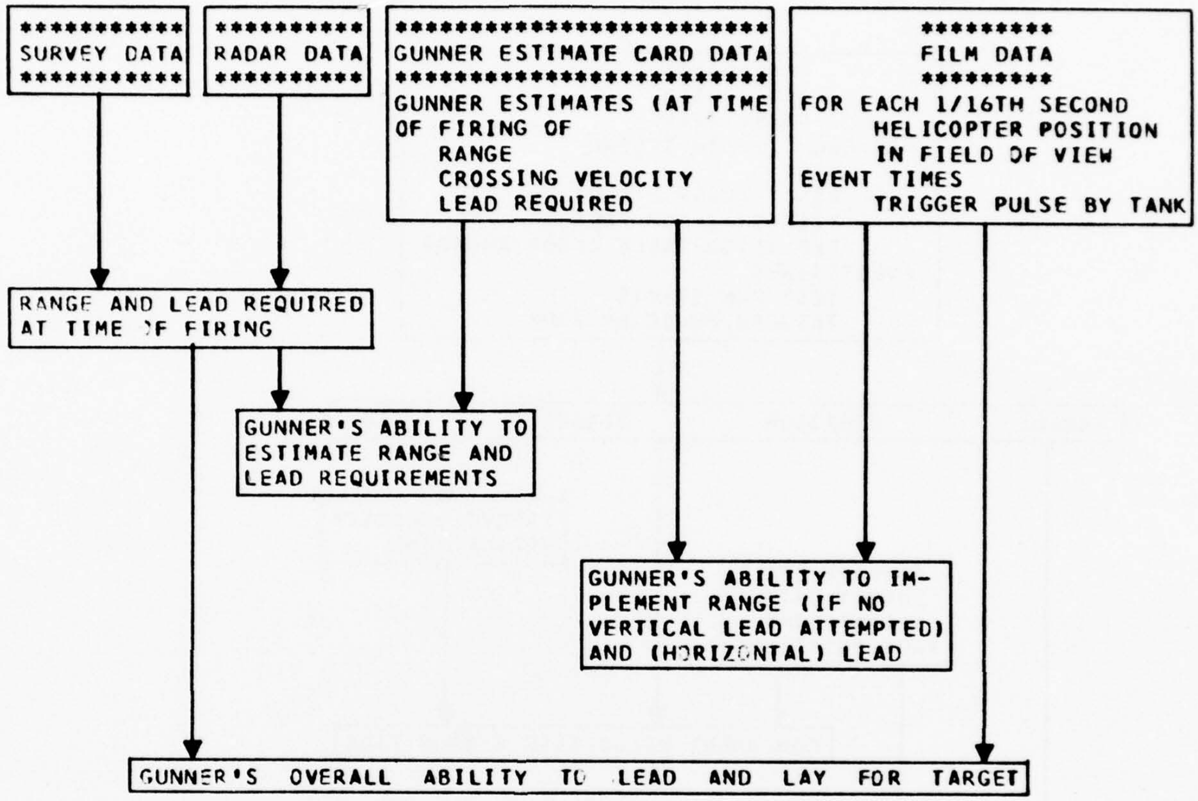

Figure 3-1. Overview of Data Reduction Approach.

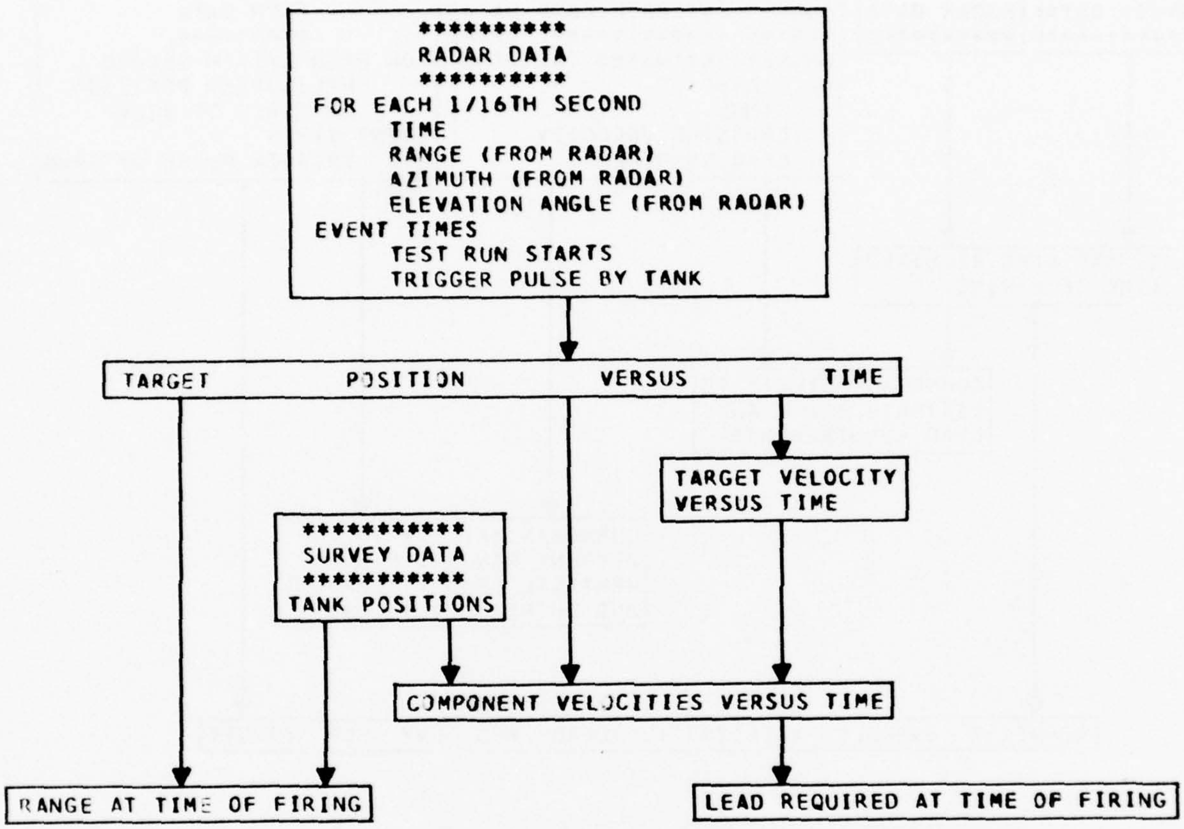

Figure 3-2. Methodology Steps for Determining Range and Required Lead at Time of Firing From Survey Data and Radar Data.

3.4 Gunner's Implementation Errors.

The gunner's implementation errors are differences at trigger pull between the calculated target position in the sight corresponding to the gunner's estimates of range and lead, and the target position in the sight as measured on the film. The vertical position, in mils, corresponding to the gunner's range estimate is calculated by the expression

$$(0.00264 \times \text{Estimated Range (meters)}) - 0.194.$$

This expression is an adequate relationship between range and superelevation on the M105D telescope reticle for the APDS round. The vertical position of the target in the sight is the difference between the vertical film reading for the center of the helicopter at trigger pull and the center of the boresight target prior to the run, converted to mils. The horizontal position, in mils, corresponding to the gunner's lead estimate is simply his lead estimate supplemented by the minor adjustment for drift corresponding to the vertical position of the helicopter in the film. (The drift adjustment is almost linearly dependent on range with a maximum value of 0.38 mil at 3000 meters.) The horizontal position of the target in the sight is the difference between the horizontal film reading for the center of the helicopter at trigger pull and the center of the boresight target prior to the run, converted to mils. The intended target position is determined by dropping down the drift line to the target position in the film, then displacing horizontally (See next paragraph.)in the direction the gunner actually applied lead, by a magnitude corresponding to the gunner's estimate of the required lead (Actually the velocity estimate X 1/3 mil/knot was used.) This assumes that the gunner always aimed his sight so that the target was on the side of the drift line he intended. This may not be a perfect assumption, but without totally reliable information indicating in which direction the gunner intended to apply lead, no better solution could be developed.

The lack of direction information associated with lead creates ambiguity for horizontal and vertical implementation errors and for lead estimation errors. In the initial analyses, implementation errors were calculated on the basis of an assumption that the gunner attempted to apply the estimated lead in the direction of apparent motion of the helicopter target. This approach was discontinued when it became apparent that the velocities were probably inadequate to indicate the proper direction, especially at low speeds. The subsequent approach was to assume that the lead estimate was to be applied in the direction indicated by the calculated horizontal crossing velocity. This approach was facilitated by the fact that gunners tended not to apply a vertical lead component. When the direction indicated by the calculated horizontal crossing velocity is wrong or the gunner applies lead in the wrong direction, the second approach can create large horizontal implementation errors and large total horizontal errors. Values reflecting these errors

have been used in later TAHOP analyses. However, the data in Appendix C presume lead was applied in the correct direction, even when the actual lead applied is in opposition to the calculated direction. The tabulations of Appendix C contain an indicator (in Column 12) which identifies the runs in which this condition occurs.

3.5 Gunner's Overall Ability to Lead and Lay.

Comparison of the gunner's actual corrections to the superelevation and lead requirements provides information concerning his overall capability to lead and lay for a helicopter target. The total errors are obtained by subtracting the superelevation and lead requirements from the offsets made by the gunner. The superelevation required, in mils, is

$$(0.00264 \times \text{Range (meters)}) - 0.194,$$

where range here is the actual range. The correct aimpoint for a stationary target has the foregoing superelevation and an appropriate horizontal offset for drift. From this point, lead at the rate of 1/3 mil per knot must be applied by moving the target in opposition to the direction of apparent motion. The offsets made by the gunner are obtained from the films. Remember, as stated in Subsection 3.4, this procedure is not the same as that used to calculate the total horizontal and vertical errors tabulated in Appendix C. The formulas, presented in Section 4, that are used for Appendix C compensate for the gunner applying lead in the wrong direction.

3.6 Data Reliability Considerations.

3.6.1 General.

One of the difficulties in analyzing the TAHOP results involved devising a method to locate and edit erroneous data. One of the more troublesome examples of bad data involved trials where multiple firing indications existed (There was supposed to be only one firing per tank per trial in the basic TAHOP.) and the film readers responded to the first indicated firing (often a target lag condition). This undoubtedly occurred because of the need to use a semi-automatic procedure for locating the film firing indications rather than spend the time required to review each film record before making a reading.

In the same vein, it would be exorbitantly time-consuming to review each film record for these types of problems. Instead, those cases where the target was being lagged by more than 5 mils were deleted. For the Constant Speed Level maneuver category 1.3% of the cases (11/858) involved lag conditions with horizontal errors greater than 5 mils, while for the Other Evasive Targets the proportion was 4.1% (13/315 cases).

Many examples are available to demonstrate that specific portions of the TAHOP data do not reflect the capabilities of well trained tank gunners to fire main gun ammunition at helicopter targets. An outstanding example of this is the horizontal error of 355.2 mils for the gunner in Tank 4 during Run 616. This error, calculated using the same procedures as for the rest of the TAHOP data, is primarily the result of an erroneous determination of helicopter velocity, 1214 knots, obtained by mathematically smoothing the radar data. (Without the mathematical smoothing the velocity data would be even worse.)

On the other hand, numerous, but far from complete, checks of various portions of the data have shown some to be reasonably correct. In addition, the analyses presented subsequently indicate trends and performance levels that it is virtually certain did not happen by accident.

Significant degradation of the TAHOP data resulted from the influence of the following factors:

a. Gunner qualifications.

b. TAHOP training phase.

c. Target velocities.

d. Gunner aim at trigger pull.

The following limited discussion of these factors related to potential degradation of the data is intended to indicate the necessity for the unusual analysis technique discussed in Subsection 5.3.1 and provide some understanding that TAHOP does not indicate the performance capabilities of well trained tank gunners so much as it provides a basis for determining a lower bound of performance.

3.6.2 Gunner Qualifications.

Although the TAHOP gunners were supposed to be qualified tank gunners, there are substantial indications that they were not what would be considered well trained. Specifically, at least one of the gunners frequently applied lead in the wrong direction and 6 of 13 gunners routinely failed to apply superelevation.

3.6.3 TAHOP Training Phase.

The TAHOP gunners, like all tank gunners in the U.S. Army, had no experience in firing against a target moving at a variety of speeds. In spite of a recognized need for training in this area, little was accomplished. The majority of test conditions involved speeds of 20 knots and under. Some of these involved an intended zero target speed, of course. For the others, where intended speeds

were 10 or 20 knots, the speed indicator on the helicopter was not reliable (Differences as large as 10 knots between the actual speed and the indicator reading later proving to have been common.) and radar data could not be processed quickly enough to give the gunners any feedback concerning their velocity estimates. As a result, in many cases when the gunners were told they had just fired at a 10 knot target, its speed was later determined to have been more nearly 20 knots.

3.6.4 Target Velocities.

The target velocities were obtained by smoothing the radar data, i.e., target azimuth, elevation, and range relative to the radar station at 1/16th second intervals. The procedure used is discussed in Subsection 3.2. Direct calculations of velocities from the indicated motion over each 1/16th second interval obviously do not produce correct velocities because many accelerations and velocities so produced are beyond the physical capabilities of the helicopter. The validity of the velocities used for this report has not been determined. These velocities are probably in error sufficiently to influence the results of the analyses but not enough generally to invalidate the broad conclusions.

3.6.5 Gunner Aim at Trigger Pull.

The gunner aim at trigger pull was recorded on the gun camera film. Prior to each run the gunner aimed at a boresight panel at approximately 1600 meters. This established his aimpoint within the frame for a condition of no range, drift, or lead correction. During the run the gunner aimed at the target with compensation for range, drift, and lead. The difference between the position of the center of the target (Gunners were instructed to aim at the center of the body in line with the vertical rotor drive shaft, and the film readers were also given the same instructions.) at trigger pull and the center of the boresight target in the boresight frame is the total compensation made by the gunner.

Some of the gunner-aim-at-trigger-pull data appear to be adequate for most TAHOP purposes. Other portions of the data appear to bear little resemblance to the films from which they were supposedly derived.

If the equipment was completely repeatable, the center of the boresight panel would appear at the same location for all runs. Discounting tank to tank and film roll to film roll variations which could result from initial setup and/or camera movement during the reloading process, there are three probable sources of run-to-run variation in boresight panel readings. These sources are:

a. Gunner aim.

b. Camera/gunner's sight alignment, influenced by:

(1) Variation in sun's direction and intensity causing variable thermal distortion.

(2) Shock from sudden starts and stops when traversing or elevating the gun.

c. Film reading errors.

The variation in boresight panel readings within a film roll is typically 0.3 mil to 0.5 mil root-mean-square in TAHOP. The TAHOP data have not been examined to determine to what extent each of the above contributes to the variation present. Although the cause of this variation cannot be definitely established, it can be observed that:

a. Gunner aim errors would tend to be random. (Gunner aim error consistency has repeatedly been demonstrated to be less than 0.1 mil root-mean-square in tests involving constraints similar to TAHOP.)

b. Thermal distortion would tend to be patterned and similar from tank to tank. Shock related errors would tend to have infrequent changes.

c. Film reading errors would compound the other effects.

The film reading requirements are most demanding for the Hover situation, where the errors are expected to be a minimum. A rough check of the data was made by re-reading the film at AMSAA for 9 Hover runs and comparing the results to the corresponding readings obtained from CDEC. (A total re-reading of the TAHOP film data is well beyond the level of effort that was planned for the analysis of the TAHOP data.) The resulting differences were only 0.15 mil root-mean-square, indicating completely adequate data for the analysis.

However, during subsequent efforts to analyze the Constant Speed Level Flight runs, problems were again noted in connection with the film data. On one roll of film examined in detail, five major film reading errors (1 mil, 1 mil, 7 mils, 8 mils, and 11 mils) were identified in a sample of 30 readings.

At this point it appears that, although some substantial film reading errors are present in the TAHOP data, much can be learned about the performance of the TAHOP gunners without re-reading the film, if considerable care is exercised in examining and interpreting the data.

4. BASIC REDUCED DATA

4.1 General.

The reduction process yielded usable basic data for about 1800 simulated firing events in a form suitable for subsequent study. This section indicates the nature of the reduced data, a sample of which is tabulated in a set of two appendixes.

4.2 Data.

Appendixes C and D each contain one sample page of reduced data. The total compilation of reduced data can be provided by AMSAA upon request. The data tabulation for which a sample page is included in the first appendix contains the following information for each test firing:

a. Column 1 - Run number, where digit following a space designates a repeat run.

b. Column 2 - Tank number.

c. Column 3 - Gunner number.

d. Column 4 - Range, in meters.

e. Column 5 - Horizontal crossing component of the helicopter speed, in knots.

f. Column 6 - Vertical crossing component of the helicopter speed, in knots.

g. Column 7 - Gunner's estimate of range, in meters.

h. Column 8 - Gunner's estimate of helicopter crossing speed, in knots.

i. Column 9 - Gunner's estimate of lead, in mils.

j. Column 10 - Gunner's range error, in meters.

k. Column 11 - Gunner's lead error, in mils.

l. Column 12 - Lead applied by gunner, in mils, followed after a space by 1 or 0 indicating respectively whether lead was or was not applied in the correct direction.

m. Column 13 - Elevation applied by gunner, in mils.

n. Column 14 - Gunner's horizontal implementation error, in mils.

o. Column 15 - Gunner's vertical implementation error, in mils.

p. Column 16 - Gunner's horizontal error, in mils.

q. Column 17 - Gunner's vertical error, in mils.

The tabulation for which a sample page is included in Appendix D includes additional data for each firing event. Corresponding lines in Appendixes C and D are for the same test event. Appendix D provides the following information for each firing:

a. Column 1 - Run number, as for Appendix C.

b. Column 2 - Tank number, as for Appendix C.

c. Column 3 - Gunner number, as for Appendix C.

d. Column 18 - Trial start time, in hours, minutes, and seconds.

e. Column 19 - Film fire time, in hours, minutes, and seconds.

f. Column 20 - Radar fire time, in hours, minutes, and seconds.

g. Column 21 - Target azimuth angle, in degrees.

h. Column 22 - Target elevation angle, in degrees.

i. Column 23 - Target approach angle, in degrees.

j. Column 24 - Total target speed (magnitude of the combination of the three component speeds), in knots.

k. Column 25 - Target closing speed, in knots.

Data labelled "ESTIMATE DATA MISSING" occur because the missing portions were not recognized as missing until after part of the data had been entered in the computer. Unlisted run/tank combinations result, in general, from more obvious data deficiencies. The complete data tabulations are all related to the basic TAHOP test and subdivide as follows:

a. Hover, 292 firing events.

b. Constant Speed Level, 871 events.

c. Constant Speed Non-Level, 283 events.

d. Constant Speed Level (Tanks canted), none.

e. Lateral (Side-to-side pendulum-type motion), none under this heading but 75 firing events involving this maneuver are included as a subset of the 315 events for other evasive targets.

f. Nap of Earth, 79 events.

g. Other Evasive Targets (Various accelerating paths), 315 events including 75 for lateral side-to-side pendulum-type motion. Data for the Constant Speed Level (Tanks canted) maneuver category exist but, at the time of publication of this report, not in an organized form lending itself to tabulation. Similarly, information for the add-on portion of the TAHOP test exists but not in a form permitting tabulation of data.

4.3 Principal Formulas.

Quantities in Appendixes C and D which are calculated from other (more basic) information, not all of which is tabulated, are those in Columns 10 through 17. Formulas used to calculate data in these columns follow. All horizontal quantities are covered together, before vertical quantities are likewise treated.

a. HORIZONTAL LEAD ESTIMATE ERROR, in mils (Column 11) = LEAD ESTIMATE, in mils (Column 9) - (1/3 Absolute Value of HORIZONTAL VELOCITY, in knots (Column 5)).

b. LEAD APPLIED HORIZONTALLY, in mils (Column 12) = - HORIZONTAL OFFSET FROM BORESIGHT, in mils + (Sine of Camera/Sight Alignment Angle For Firing Tank X VERTICAL OFFSET FROM BORESIGHT, in mils), where the camera/sight alignment angle has the following, tank-dependent, values:

TANK NUMBER	RADIANS	DEGREES
1	0.0125	0.72
2	0.0231	1.32
3	0.0491	2.81
4	0.0148	0.85
5	0.0015	0.09
6	0.0317	1.82

Whether horizontal lead is applied in the correct direction is determined by whether LEAD APPLIED HORIZONTALLY (Column 12) and HORIZONTAL CROSSING COMPONENT OF THE HORIZONTAL SPEED (Column 5) have the same sign or different signs.

c. HORIZONTAL IMPLEMENTATION ERROR, in mils (Column 14) = (Absolute Value of LEAD APPLIED HORIZONTALLY, in mils (Column 12)) - HORIZONTAL LEAD ESTIMATE, in mils (Column 9).

d. HORIZONTAL ERROR (Column 16) = HORIZONTAL LEAD ESTIMATE ERROR, in mils (Column 11) + HORIZONTAL IMPLEMENTATION ERROR, in mils (Column 14).

e. RANGE ESTIMATE ERROR, in meters (Column 10) = ESTIMATED RANGE, in meters (Column 7) - ACTUAL RANGE, in meters (Column 4). RANGE ESTIMATE ERROR (Column 10) is multiplied by 0.00264 to obtain corresponding error in mils.

f. VERTICAL VELOCITY ERROR, in mils = - 1/3 VERTICAL VELOCITY, in knots.

g. ELEVATION APPLIED, in mils (Column 13) = VERTICAL OFFSET FROM BORESIGHT, in mils.

h. VERTICAL IMPLEMENTATION ERROR, in (meter) range units = - ((VERTICAL OFFSET FROM BORESIGHT, in mils - 0.196/0.00264) - ESTIMATED RANGE, in meters (Column 7).
VERTICAL IMPLEMENTATION ERROR in range units is multiplied by 0.00264 to obtain corresponding error in mils (Column 15).

i. VERTICAL ERROR, in mils (Column 17) = RANGE ESTIMATE ERROR, in mils + VERTICAL IMPLEMENTATION ERROR, in mils (Column 15) + VERTICAL VELOCITY ERROR, in mils.

5. RESULTS OF ANALYSES

5.1 General.

A primary objective of TAHOP data analyses has been to develop information suitable for use in a variety of potential applications involving hit capabilities of tanks firing against moving targets, especially aerial targets. For example, the calculation of hit/kill probability estimates for the T-62 tank main gun firing APDS rounds against a helicopter is one such application. As indicated earlier, the need for specifically such estimates led to the conduct of the TAHOP test.

Inspection of the error sources normally considered in estimating hitting probability for a stationary tank firing at a stationary target reveals that all of these errors apply to a moving target situation as well (and also apply equally well to a ground target and a low flying aerial target such as those considered in TAHOP). One of these errors, however, lay error, can be considered to take on an expanded meaning for firing against a moving target, as discussed below.

For a T-62 firing at a moving target, one must, beyond what is considered in firing at a stationary target, take account of the fact that the gunner is required both to determine where he should lay (i.e., estimate a required lead) and to lay (i.e., implement the estimated lead). Determining where to lay is not a problem for stationary targets, since the gunner generally attempts to lay on the target center (although he will ordinarily do so in an imperfect manner). To calculate hit probabilities against moving targets, one thus needs both data on lead errors (that do not apply to tanks firing against stationary targets) and data on implementation (lay) errors (whose numerical values would not be expected to be the same as the lay error values normally used for stationary targets). TAHOP was designed to permit inferring these component errors from an overall combined value measurable in the test. In addition, range estimation errors occurring in TAHOP must be analyzed. These errors were included as part of the vertical total errors measured in the test, and one needs to remove range estimation errors from vertical total errors to determine what the corresponding vertical lead and implementation errors were. Range estimation errors normally used for calculations of hit probabilities against stationary targets are applicable to moving targets as well, and are not superseded by the range estimation errors specifically observed in TAHOP. In view of the above, the delivery accuracy errors of interest are the overall horizontal and vertical errors, and the range estimate, lead estimate, and implementation (lay) components.

This section documents the various analyses that were made of the basic reduced data. (Actually, the first phase of the analyses was carried out with data that differ somewhat from the finalized version covered by Appendixes C and D.) The analyses were carried out in roughly two phases. The first phase involved to a considerable extent systematic calculations of means and standard deviations for various test conditions and did not directly provide a complete set of results suitable for detailed calculations of hit probabilities. It indicated some trends and led to the identification of difficulties in certain areas. Initial calculations of means and standard deviations were based on standard procedures. In the second phase, additional analyses were undertaken to resolve various difficulties and to generate input information more directly useful for hit probability determinations. Unfortunately, the effort was time-consuming and was thereby limited to consideration of the basic TAHOP test data for the Hover and Constant Speed Level maneuver categories. Results presented in the section for the other maneuver categories and the add-on portion of the test are based on data developed in the first phase of the analyses.

5.2 General Results From First Phase Analyses Of Basic TAHOP Data For All Maneuver Categories

5.2.1 Introduction

This subsection discusses the earliest analyses made of the data from the basic TAHOP experiment. Results are useful, even though they are sometimes based on formulas differing somewhat from the final formulas documented in Subsection 4.3.

Because of some of the problems mentioned in Subsection 3.6, it was advisable to examine the TAHOP data to remove bad or substantially questionable data. Twenty-eight simulated firings, although included in the tabulations referred to in Appendixes C and D, were not used in any of the analyses. These firings were the following:

a. Hover - Run 355 firings for all tanks, and individual firings for Tank 1 in Runs 13, 43, and 361 as well as for Tank 5 in Run 205.

b. Constant Speed Level - Run 354 and 616 firings for all tanks, and individual firings for Tank 5 in Run 80.

c. Constant Speed Non-Level - Run 357 firings for all tanks, and individual firing for Tank 4 in Run 47.

d. Other Evasive Targets - Run 378 firings for all tanks.

Another group of data not used at all in most of the initial analyses was related to the gunners who frequently made no obvious attempt to apply superelevation, even though their range estimates seemed reasonable. Figure 5-1 shows the mean and standard deviation of the vertical errors, for the Constant Speed Level maneuver, for all gunners versus the gunners who usually applied superelevation. Gunners 2, 12, 14, 15, 16, and 17 seldom applied superelevation. Gunners 1, 4, 5, 7, 9, 11, and 13 usually applied superelevation; however, Gunner 5 usually applied about 2.9 mils, appropriate for 1200 meters, independently of his range estimate. Gunner 5 is included in the "gunners usually applying superelevation" group in Figures 5-1 and 5-2 but was removed when this was judged appropriate in connection with the second phase analyses of Hover and Constant Speed Level maneuvers. The remainder of the initial analyses, i.e., all analyses except those related to Figures 5-1 and 5-2, utilized both horizontal and vertical data for Gunners 1, 4, 5, 7, 9, 11, and 13 only. Since Figure 5-2 shows no major consistent difference in horizontal performance between the two groups of gunners, the second phase analyses of Hover and Constant Speed Level maneuvers covered all gunners when errors related to horizontal phenomena were examined.

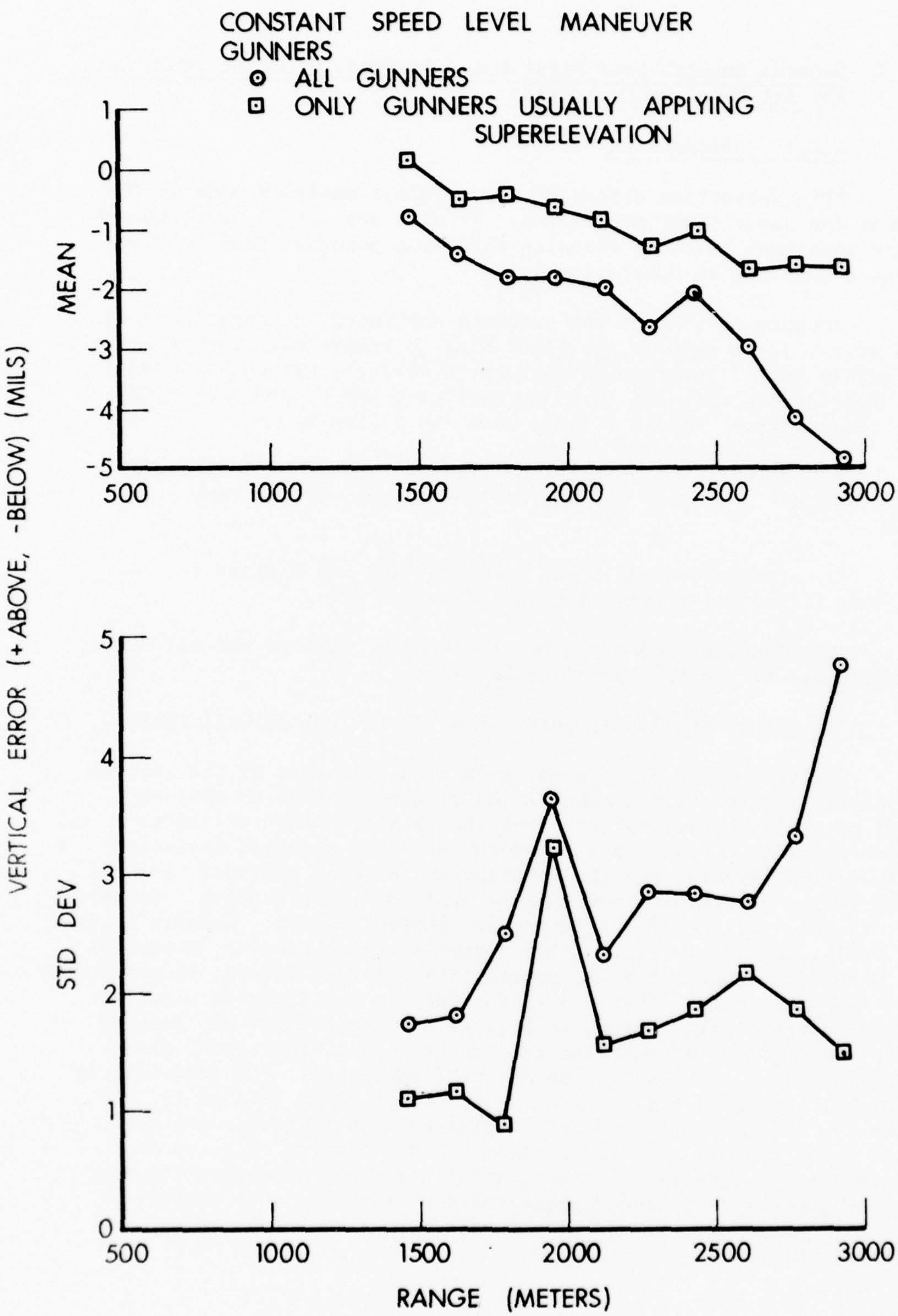

Figure 5-1. Comparison of Vertical Errors: Gunner Differences.

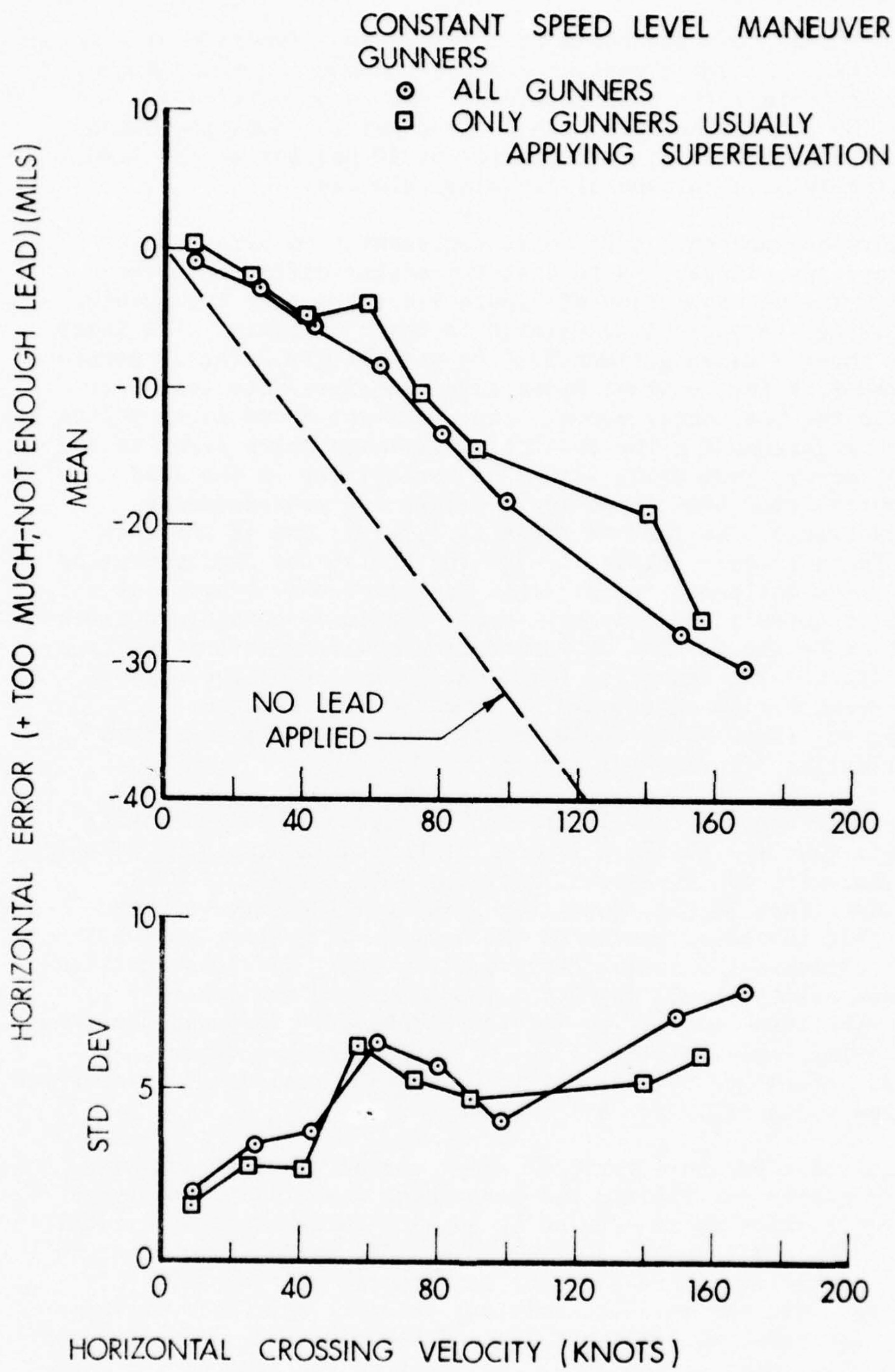

Figure 5-2. Comparison of Horizontal Errors: Gunner Differences.

5.2.2 General Observations On All Maneuvers

Figure 5-3 shows the horizontal errors as a function of horizontal crossing velocity. The upper portion shows a tendency on the average for the gunner to apply half the lead required. The lower portion shows a mixed pattern for the variability with a trend for the Constant Speed Level maneuver to have a standard deviation of 20 percent of the lead required for the related horizontal crossing velocity.

Figure 5-4 presents horizontal implementation error versus horizontal crossing velocity. Note that the scales differ from those in Figure 5-3. The upper portion of Figure 5-4 shows that the gunners tend on the average to apply lead related to their estimate. The lower portion again shows a mixed pattern for the variability. The 20 percent of correct lead fits the Constant Speed Level maneuver data less well than it did for the horizontal error. Four Constant Speed Level points are about the same magnitude for the horizontal implementation error as for the horizontal error, indicating either no variability in the lead estimate or correlation between estimate errors and corresponding implementation errors. Neither of these is likely. One of the data points indicates a larger variability for the horizontal implementation error than for the horizontal error; this can occur only because of a real correlation between the estimate errors and corresponding implementation errors or by the misleading implication sometimes resulting from small sample sizes. The remaining three data points (for the highest velocities) are more like what would be expected with the component variability (horizontal implementation error) being less than the total variability (horizontal error).

Figure 5-5 presents velocity estimate error versus crossing velocity. Note that the abscissa is not the horizontal crossing velocity, but crossing velocity and horizontal crossing velocity are closely related for most cases in the TAHOP test. The upper portion of the figure shows that the basic source of the underleading in Figure 5-3 is failure to estimate the target crossing velocity. The lower portion shows less variability, i.e., less of a dependence of the gunner's capability to estimate velocity on the target maneuver than was the case for the horizontal implementation error or the horizontal error. An estimate of 20 percent of the correct velocity is a reasonable description of the observed variability for all maneuvers.

Figure 5-6 presents vertical error versus vertical crossing velocity, in a manner paralleling the horizontal error plots in Figure 5-3. The upper portion shows a trend by gunners to ignore the vertical lead requirements in all maneuver situations. The variability seems to reflect small sample size more than any fundamental relationship. If the gunners truly did not react to vertical velocity and their estimate of range and corresponding implementation of the required superelevation were correct, a residual variability, dependent on the span of the data

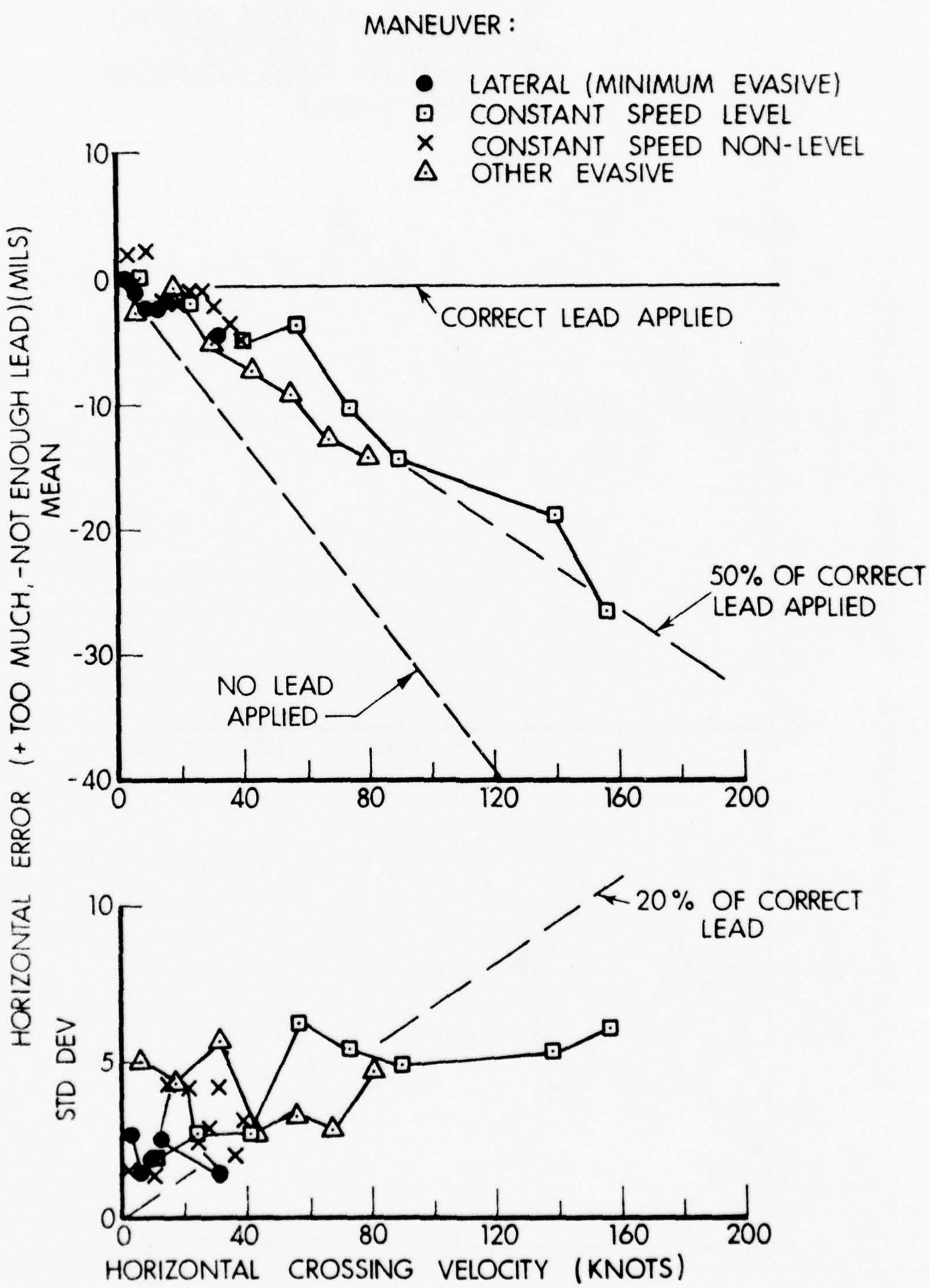

Figure 5-3. Horizontal Error Versus Horizontal Crossing Velocity.

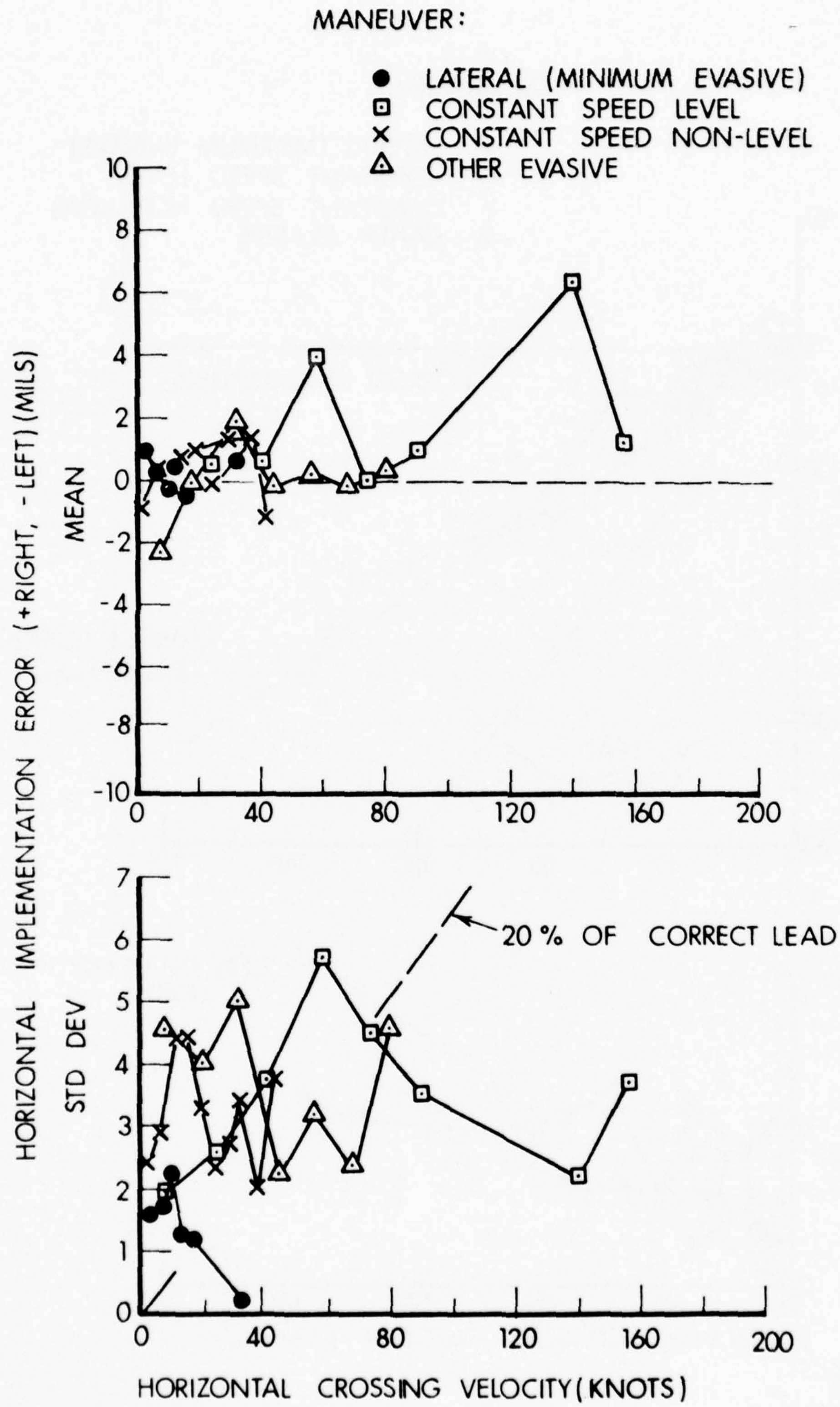

Figure 5-4. Horizontal Implementation Error Versus Horizontal Crossing Velocity.

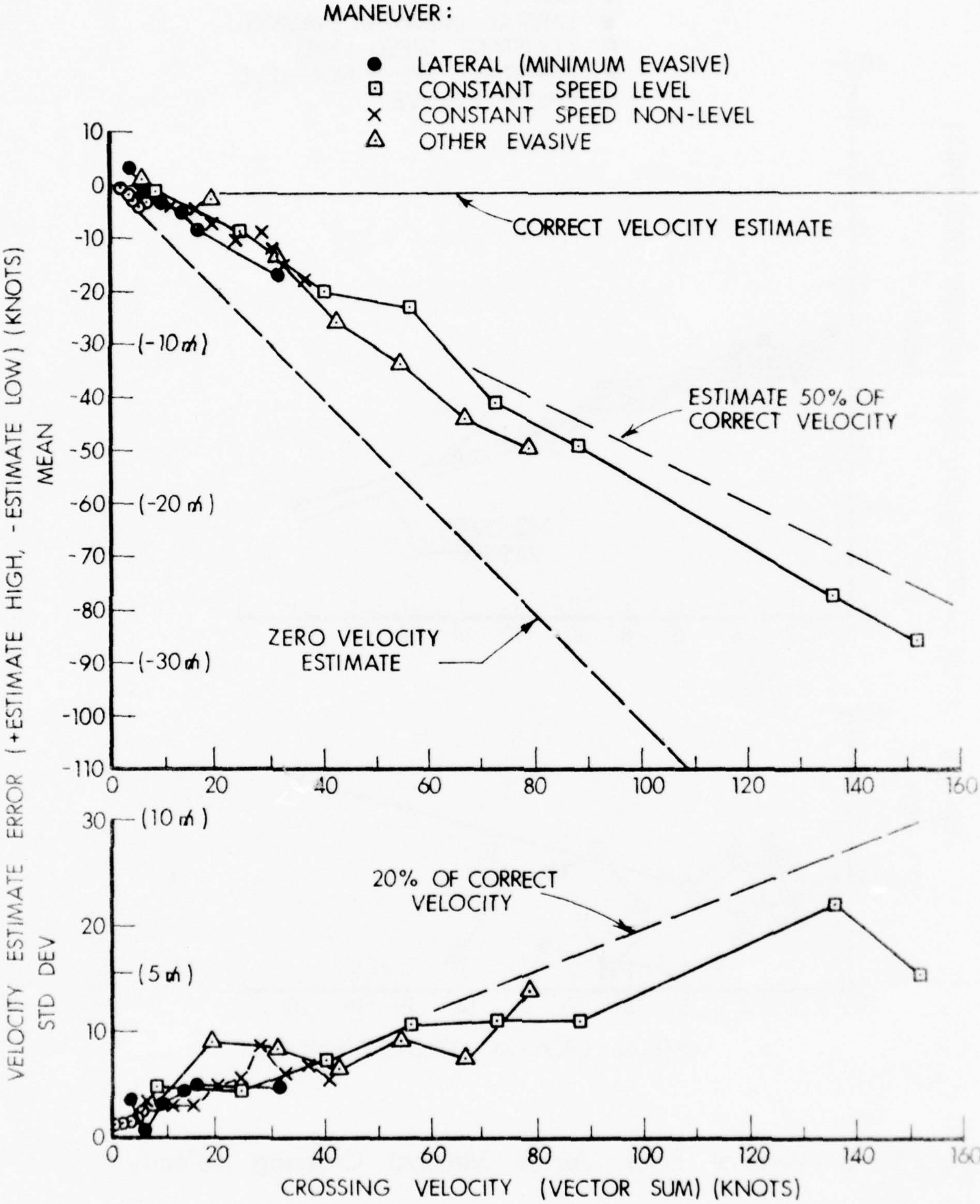

Figure 5-5. Velocity Estimate Error Versus Crossing Velocity.

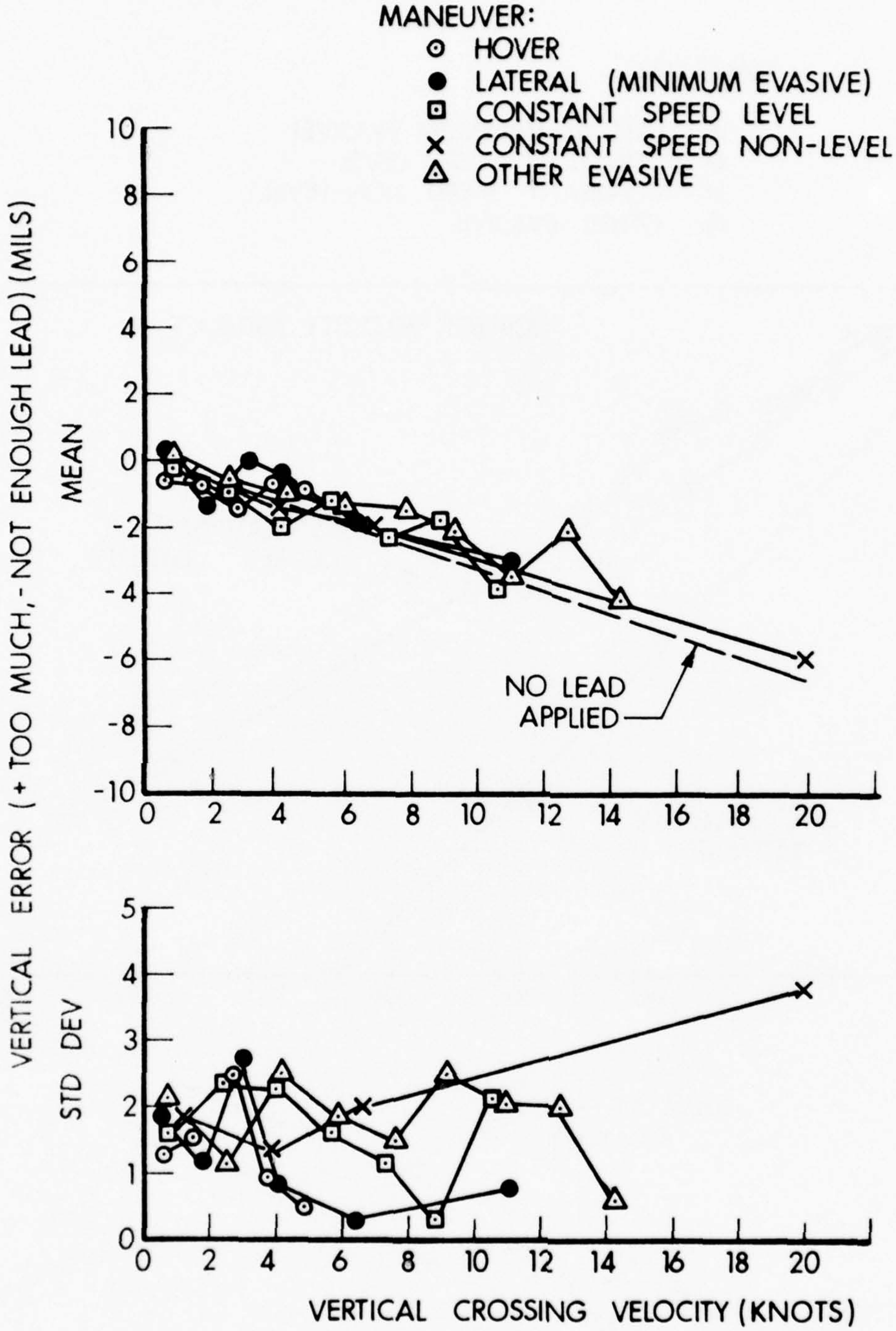

Figure 5-6 Vertical Error Versus Vertical Crossing Velocity.

for the sample and vertical velocities within that span, would appear as variability though it really should be associated with the trend in the mean of the vertical error.

Figure 5-7 is similar to Figure 5-6 in that it also presents vertical error as a function of vertical crossing velocity. In Figure 5-7 positive errors correspond to impacts above the center of the target, whereas in Figure 5-6 positive errors correspond to impacts "ahead", i.e., below the center of the target when the helicopter is descending. The data indicate a slight tendency for a negative impact; this is the result of gunners underestimating the ranges to the target, as is discussed in connection with Figure 5-8. The increased values for dispersions in Figure 5-7 compared to Figure 5-6 are the result of the consistency of error magnitude contributed by vertical velocity but with alternating signs in the coordinate system of Figure 5-7 (as opposed to the trend in the bias in the overlead/underlead system of Figure 5-6).

The range estimation error versus range data presented in Figure 5-8 show a couple of unusual data points for Other Evasive Targets at the shortest ranges, plus a trend to underestimate the range (greater underestimation at greater ranges). The variability is considerable but fits the 17 percent associated (prior to TAHOP) with stadia range finders. Range estimation errors are discussed in greater detail in connection with the comprehensive examination of data for the Hover situations.

5.3 Hover.

5.3.1 Introduction.

This subsection documents a reasonably complete analysis of basic TAHOP data indicating gunner performance against a hovering helicopter. The specific errors of interest are as follows:

a. Horizontal error.

b. Lead estimate error component of horizontal error.

c. Implementation error (lay error) component of horizontal error.

d. Vertical error.

e. Range estimate error component of vertical error.

f. Lead estimate error component of vertical error.

g. Implementation error (lay error) component of vertical error.

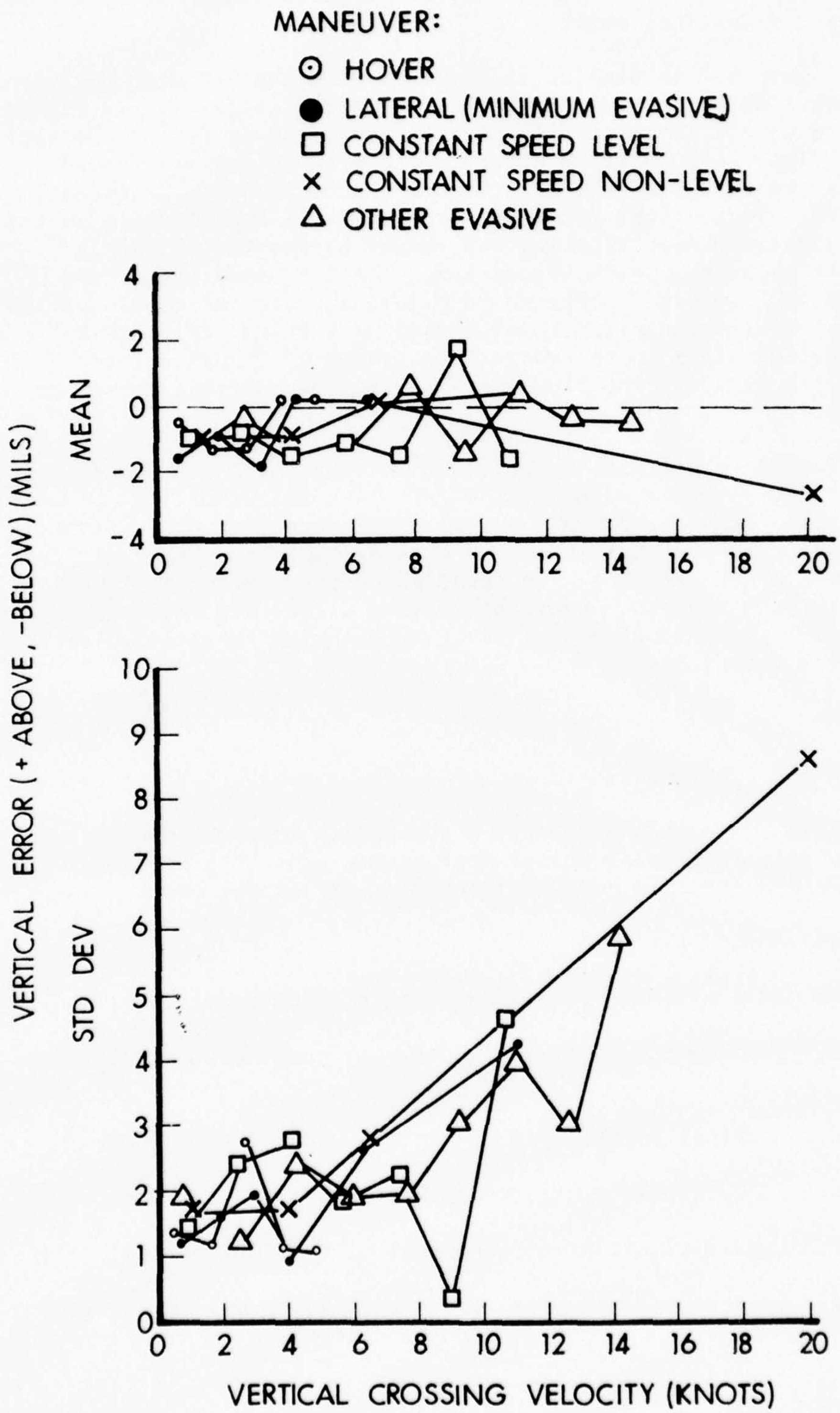

Figure 5-7. Vertical Error vs Vertical Crossing Velocity.

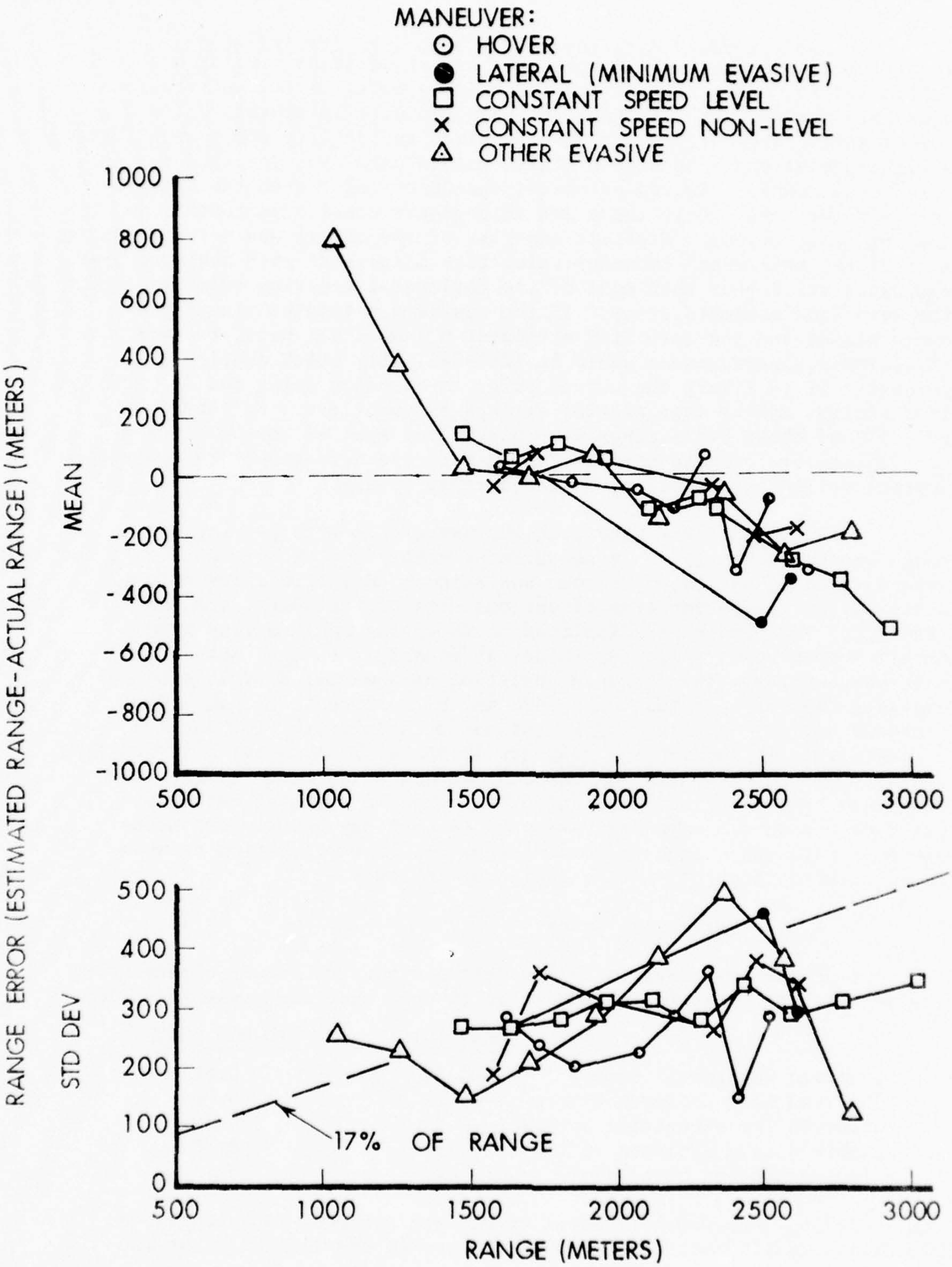

Figure 5-8. Range Error vs Range.

Basic reduced data cover 292 (simulated) firing events involving test situations in which the target helicopter pilot was instructed to hover. In the case of a few events, either gunners made gross mistakes or the data have not been properly interpreted. An unreasonably large effort would be required to identify and correct data misinterpretations. Because of this, usable data are available for only 281 firing events. In 248 of these, the gunner estimated the lead required to be zero. Only these 248 firings are considered further in most of what follows. Explicit analysis of the others was not undertaken. Most of the horizontal crossing velocities associated with non-zero lead estimates are higher than most of the horizontal crossing velocities for the zero lead estimate group. If the non-zero estimates always produced misses and the zero lead estimates produced all hits, the error in estimating performance would be (281-248)/281, which equals 12 percent. It is likely the actual error involved in using the 248 zero lead firings rather than all 281 firings is much less. Furthermore, only 130 of these 248 firings were usable for most of the analyses of vertical errors because some of the gunners did not attempt to apply the superelevation corresponding to their range estimate.

Because of the many problems associated with getting measurements with negligible measurement error (See Subsection 3.6.), the methods used to estimate the mean and standard deviation, for normal distributions representative of various sets of test data, are non-standard. The parameters displayed in the paragraphs dealing with detailed test results are the values at roughly the 16th, 50th, and 84th percentiles. The standard deviation of a normal distribution is one-half the spread between the 16th and 84th percentiles, and thus standard deviations were readily estimated in this way from the two percentiles. The median and mean are identical in a normal distribution, and 50th percentiles have consequently been used as mean values. The advantage of the technique selected, as compared to using estimates based on the sample mean and variance, is that any grossly erroneous piece of data can change the estimate by only the separation between consecutive data points in the region of interest.

5.3.2 Horizontal Errors.

Parameters describing the distributions of errors observed in the 248 firings constituting the selected data base are presented below:

	MEAN (MILS)	STD DEV (MILS)
Observed Horizontal Errors	+0.25	0.81
Observed Lead Estimate Errors	+0.15	0.76
Observed Implementation Errors	-0.03	0.39
Combined Lead Estimate and Implementation Errors	+0.12	0.85

The preceding observed horizontal errors and observed implementation errors are referenced to the coordinate system and indicate that the

round would have passed to the right of the target for positive errors and to the left for negative errors. Note that the distribution of lead estimate errors in this instance is the distribution of actual leads required, because all the firings involved lead estimates of zero.

The distribution produced by combining the lead estimate and implementation errors is an estimate of the distribution of horizontal errors. Combined errors were calculated as follows:

a. Mean = +0.15 + (-0.03) = +0.12 (compared to +0.25 observed).

b. Std Dev = $\sqrt{0.76^2 + 0.39^2}$ = 0.85 (compared to +0.81 observed).

If the individual error components are independent of each other, total errors obtained by the above procedure should agree with observed total errors. Since the synthesized horizontal errors and the observed horizontal errors are in good agreement, the observed distributions of lead estimate errors and implementation errors can be presumed to be independent and described by the values listed.

Additional investigations to determine if lead estimate errors or implementation errors are functions of range, gunner, and horizontal crossing velocity failed to indicate any substantial dependence of the errors on these factors. Therefore, the horizontal lead estimate errors and horizontal implementation errors for firings against hovering helicopters can be represented for hit probability estimate purposes as follows:

a. The distribution of horizontal lead estimate errors for the helicopters hovering in TAHOP can be described as a normal distribution with mean equal to zero and a standard deviation of 0.76 mil. The relatively small mean in the test data is negligible in its effect. This mean results from actual non-zero horizontal velocities as well as velocity measurement errors. (For zero lead estimates, the lead errors that come from the analysis of the test data reflect only the measured velocities, not any capability of the gunners.) A standard deviation of 0.76 mil in lead is equivalent to, and results from, a standard deviation of 2.27 knots (or 3.83 feet per second) in crossing velocity. Such a distribution of crossing velocities is not a necessary characteristic of hovering flight. It is clear that a helicopter can hover over a particular location without significant displacement or requirement for lead; it is less clear whether a pilot on a given occasion has reason to do so. The distribution of horizontal crossing velocities appropriate for hovering helicopters in combat may differ from those observed in TAHOP, either because of velocity measurement errors which are believed to be a substantial portion of observed velocity variation (See Subsection 3.6.4.) or because velocities may depend on the helicopter type and/or its tactical employment. Thus, while a universal estimate for the distribution of horizontal lead estimate

errors for tanks firing against hovering helicopters is not available from TAHOP, the standard deviation of 0.76 mil (together with a zero mean) is thought to be an upper bound for applications involving a tank with a high velocity APFSDS round. However, since the horizontal crossing velocity of the hovering helicopter is a significant factor in determining the hitting probability, there is a problem in using this upper bound for applications where hitting capabilities of tanks could be thereby appreciably underestimated. This problem was addressed in a recent application of emerging TAHOP results (Reference 5) in which two sets of hitting probabilities for tanks firing at hovering helicopters were calculated. The two sets of hitting probabilities incorporated in the one case what is considered to be an upper bound value of lead estimate error (i.e., the TAHOP value of 0.76 mil) and in the other case what is estimated to be a practical lower bound value (i.e., 0.19 mil). A significant change in hitting probability was obtained. In other applications, it is appropriate to attempt to estimate the degree of helicopter stability at hover in relation to that recorded in the TAHOP test in order to more correctly estimate lead estimate error. Otherwise, use of the 0.76 mil value directly supported by the TAHOP test data would, of course, be the only alternative.

b. The horizontal implementation errors for the hovering helicopters in TAHOP are considered to be described by a normal distribution with a mean equal to zero and a standard deviation of 0.36 mil. The relatively small mean in the test data is negligible in its effect. The reduction of the standard deviation from 0.39 mil for the test data to 0.36 mil is the result of removing a 0.15 mil standard deviation for film reading errors from the test data. ($\sqrt{0.39^2 - 0.15^2} = 0.36$.) The lack of dependence of the implementation error on range is unusual. The corresponding error for stationary versus stationary firings (lay error) has tended in other tests to follow the angular size of the target, i.e., to be small at long ranges and large at short ranges. In addition, the vertical implementation error for Hover firings in TAHOP indicates a range effect. Because of additional comparisons to be made to the vertical implementation error, the remainder of the discussion of horizontal implementation error is presented in Subsection 5.3.6.

More detailed information concerning the horizontal errors and their components follows in Subsections 5.3.3 through 5.3.5.

5.3.3 Detailed Data Concerning Horizontal Lead Estimate Error.

Analysis of data for the 248 firings associated with a zero lead estimate yielded the following results:

	HORIZONTAL LEAD ESTIMATE ERROR		
	-1 STD DEV	MEAN	+1 STD DEV
KNOTS	-2.25	+0.44	+2.29
MILS	-0.75	+0.15	+0.76

In addition, the possible dependence of the lead estimate error in knots on range and gunner was investigated. Related information is tabulated below:

	HORIZONTAL LEAD ERROR (KNOTS)		
RANGE (METERS)	-1 STD DEV	MEAN	+1 STD DEV
UNDER 1900	-1.90	+0.70	+2.43
1900 THROUGH 2400	-3.05	-0.08	+2.11
OVER 2400	-0.81	+0.74	+2.25
GUNNER (SAMPLE SIZE)			
1 (25)	-3.10	+0.25	+1.65
2 (28)	-2.43	-0.04	+2.11
4 (9)	-1.11	+1.13	+2.62
5 (21)	-2.50	+1.34	+2.58
7 (25)	-2.31	+0.06	+1.75
9 (29)	-1.65	+0.19	+1.75
11 (16)	-1.40	+1.14	+2.81
12 (21)	-1.49	+0.37	+2.37
13 (26)	-2.23	+0.83	+2.68
14 (18)	-2.66	-0.54	+2.68
15 (8)	-2.25	+0.64	+2.60
16 (9)	-1.44	+1.34	+3.51
17 (13)	-1.96	+0.27	+1.86

No obvious effect of range or gunner is apparent.

5.3.4 Detailed Data Concerning Horizontal Implementation Error

Basic data were analyzed according to two alternative assumptions for interpreting signs:

a. A left or right (L/R) case where a positive error means the round would have passed to the right, and a negative error to the left, of the aim point regardless of the direction of motion of the target helicopter.

b. An overlead or underlead (O/U) case where a positive error means the round would have passed in front of, and a negative error behind, the aircraft.

Both assumptions are of interest because, if the gunner actually shaded his aim by applying lead in the direction appropriate for target motion, the standard deviation associated with the overlead or underlead

convention would be smaller than with the left or right convention. Results for the two cases are as follows:

	HORIZONTAL IMPLEMENTATION ERROR (MILS)		
	-1 STD DEV	MEAN	+1 STD DEV
LEFT OR RIGHT (L/R)	-0.39	-0.03	+0.39
OVERLEAD OR UNDERLEAD (O/U)	-0.34	+0.06	+0.45

The above indicates no tendency of the gunners to attempt to lead the target. The possible dependence of the implementation error for the left or right case on range, gunner, and horizontal crossing velocity of the target was also examined. Results are shown in the following tabulations:

	HORIZONTAL IMPLEMENTATION ERROR,L/R (MILS)		
RANGE (METERS)	-1 STD DEV	MEAN	+1 STD DEV
UNDER 1900	-0.43	-0.10	+0.39
1900 THROUGH 2400	-0.32	+0.02	+0.51
OVER 2400	-0.33	-0.02	+0.39
GUNNER (SAMPLE SIZE)			
1 (25)	-0.20	+0.04	+0.25
2 (28)	-0.23	+0.19	+0.70
4 (9)	-0.33	+0.13	+0.54
5 (21)	-0.49	-0.05	+0.38
7 (25)	-0.33	-0.17	+0.02
9 (29)	-0.55	-0.05	+0.25
11 (16)	-0.42	-0.05	+0.94
12 (21)	-0.45	-0.10	+0.56
13 (26)	-0.34	-0.15	+0.34
14 (18)	-0.12	+0.13	+0.38
15 (8)	-1.20	-0.27	+0.41
16 (9)	-0.76	+0.02	+0.34
17 (13)	-0.19	+0.11	+1.27
HORIZONTAL CROSSING VELOCITY (KNOTS)			
UNDER 1.5	-0.40	-0.01	+0.39
1.5 THROUGH 3.0	-0.39	-0.09	+0.37
OVER 3.0	-0.23	+0.13	+0.58

No significant dependence of the implementation error on range, gunner, or horizontal crossing velocity is apparent.

5.3.5 Detailed Data Concerning Horizontal Error.

The horizontal total error was determined, for the left or right assumption, to be as follows:

HORIZONTAL ERROR, L/R (MILS)		
-1 STD DEV	MEAN	+1 STD DEV
-0.63	+0.25	+0.98

Note that this is equivalent to (and is the source of) the mean of 0.25 mil and standard deviation of 0.81 mil, discussed in Subsection 5.3.2.

5.3.6 Vertical Errors.

As previously mentioned, the data base of interest here is 130 firings compared to the 248 firings available for the horizontal error analyses. Gunners 2, 12, 14, 15, 16, and 17 consistently failed to apply superelevation. Gunner 5 consistently applied superelevation for 1200 meters independently of his range estimate. Vertical implementation errors were not determined for Gunners 2, 12, 14, 15, 16, and 17, while Gunner 5 had smaller than normal vertical implementation errors probably because the reticle is distinctly marked at 1200 meters and he concentrated on only this one vertical position. The following discussion of errors is limited to the 130 firings for the other gunners (1, 4, 7, 9, 11, and 13) except for errors not involving the vertical implementation error. The exceptions are noted as they occur.

Vertical velocity measurements have been shown to be unreliable (See Subsection 3.6.). At this time, it is not known whether most vertical velocities are substantially in error or whether the substantial errors are infrequent. Though little credibility is presently associated with the vertical velocities, the following discussion does not take note of this problem until the portion covering interpretation of the data.

The overall characterization of the data related to vertical errors observed in the sample with 130 firings is presented below:

	MEAN (MILS)	STD DEV (MILS)
Observed Vertical Errors	-0.49	1.14
Observed Range Estimate Errors	-0.39	0.83
Observed Lead Estimate Errors	-0.09	0.53
Observed Implementation Errors	+0.06	0.53
Combined Range Estimate, Lead Estimate, and Implementation Errors	-0.42	1.12

The preceding vertical errors are referenced to the coordinate system and indicate that the round would have passed above the target for positive errors and below for negative errors.

The distribution obtained by combining the range estimate, lead estimate, and implementation errors is an estimate of the vertical errors. This distribution's parameters were calculated as follows:

a. Mean = (-0.39) + (-0.09) + (+0.06) = -0.42 (compared to -0.49 observed).

b. Std Dev = $\sqrt{0.83^2 + 0.53^2 + 0.53^2}$ = 1.12 (compared to 1.14 observed).

If the individual components are independent of each other, the synthesized vertical errors should agree with observed vertical errors. Since the synthesized vertical errors and the observed vertical errors are in good agreement, the observed distributions of range estimate errors, lead estimate errors, and implementation errors for firings against hovering helicopters can be presumed to be independent and described by the values listed.

Additional investigations to determine if range estimate errors, lead estimate errors, or implementation errors are functions of range, horizontal velocity, vertical velocity, or gunner indicated dependence of range estimate errors and implementation errors on range. These relationships are shown below:

RANGE (METERS)	RANGE ESTIMATE ERROR (PERCENT OF RANGE) MEAN	STD DEV	VERTICAL IMPLEMENTATION ERROR (MILS) MEAN	STD DEV
UNDER 1900	- 3	15	+0.17	0.73*
1900 THROUGH 2400	- 7	17	0.00	0.47*
OVER 2400	-11	13	+0.04	0.32*

Standard deviations marked with an asterisk are less than calculated from the film data because a 0.15 mil standard deviation film reading error was removed.

The vertical error components, i.e., range estimate errors, vertical lead estimate errors, and vertical implementation errors, can be described as follows:

a. Prior to TAHOP, the AMSAA representation of the distribution of range estimate errors was a normal distribution with zero mean and 17 percent standard deviation. The TAHOP data suggest a tendency to underestimate the range but TAHOP is not an adequate source of range estimate data for many reasons, the most significant one being that the gunners were not exposed to the variety of targets they would have to cope with in combat. Therefore, the minor differences between the TAHOP range estimate errors and the prior characterization of range estimate errors do not provide a basis for changing or even substantially questioning the previous characterization.

b. The vertical lead estimate errors are strictly determined from the vertical velocities. In the absence of some confidence in the accuracy of the measurements of vertical velocity, the recorded values must remain suspect. However, it is unlikely that the actual vertical velocities in TAHOP were in general greater than the measurements indicate (i.e., a zero mean and a standard deviation of 0.53 mil). The sensitivity of hitting probability to variations in vertical velocity estimate error was investigated in the set of calculations mentioned in Subsection 5.3.2 where horizontal velocity estimate error is discussed. The TAHOP vertical velocity estimate value of 0.53 mil was taken as an upper bound for APDS rounds and 0.14 mil was estimated to be a practical lower bound. As noted in Subsection 5.3.2, a significant change in hitting probability was found. Thus, in other applications, an attempt to estimate the degree of helicopter stability at hover in relation to that in the TAHOP test is in order with respect to vertical as well as horizontal motion. Otherwise, use of the 0.53 mil value directly supported by the TAHOP test data would seem to be a necessary alternative.

c. The implementation errors observed for simulated firings against the hovering broadside target are somewhat contradictory. The horizontal implementation errors are smaller than one might expect, considering the large size of the AH-1G target in the horizontal direction, though larger than the majority of lay errors previously experienced against stationary targets which are smaller than the horizontal broadside of the helicopter. The horizontal implementation errors also indicate negligible dependence on range (apparent target size). The vertical implementation errors, on the other hand, are much greater than one would expect in view of the target height; although the vertical target is smaller, the vertical errors are equal to or larger than the horizontal errors. In addition, vertical implementation errors show a range dependence even greater than can be explained by the changing apparent size of the target.

Figure 5-9 shows the shape and size of the AH-1G exposing its side as it did for nearlyall the TAHOP simulated firings in the Hover category. The target has an entire length of 13.5 meters and a body length of 6.9 meters. The target height is 3.5 meters from the skid to the centerline of the rotor, 2.8 meters for the body and

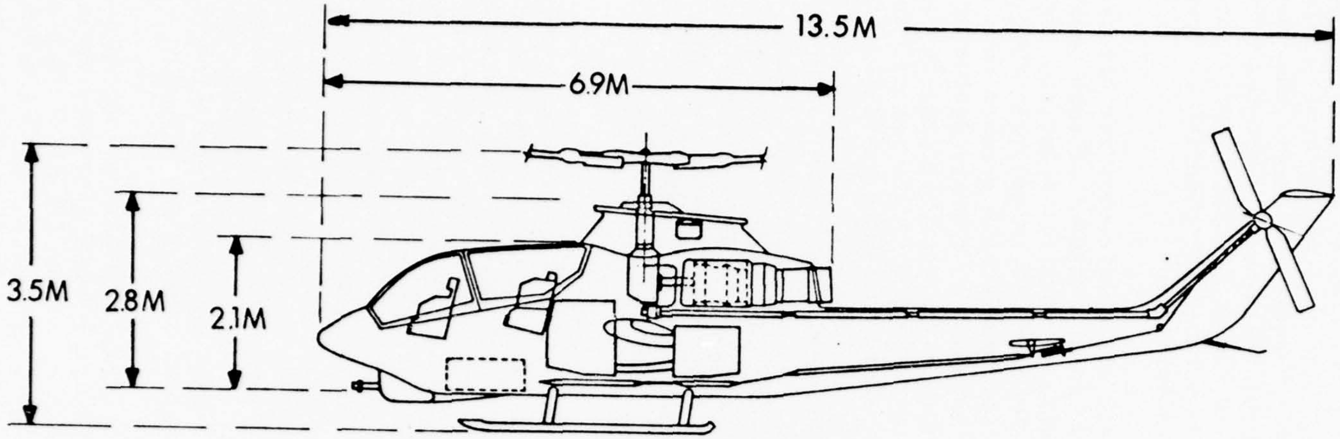

Figure 5-9. Side View of AH-1G Helicopter.

cowling, and 2.1 meters for the body only. Gunners were instructed to aim at the center of the body in line with the rotor axis. It is considered probable that they used as their target the helicopter body, though sometimes vertical aiming may have been based on the body and cowling. In any case, the vertical target dimension considered by the gunner was certainly never greater than the distance from skid to centerline of rotor.

Figure 5-10 shows the gunner lay errors that one would expect according to target size, based on experience prior to TAHOP. The 2.3 meter dimension is included for reference, since it is associated with the standard (2.3 X 2.3 meter or 7.5 X 7.5 foot) tank target. Implementation errors from the TAHOP test are also shown in the figure.

The observed horizontal implementation errors (for 248 firings) were each compared to half the body length and half the entire length of the target helicopter to determine the frequency of the gunner's aim being on target. Vertical implementation errors (for 130 firings) were similarly processed with reference to various target heights. For each implementation error checked, ranges were taken to be alternatively the shortest and longest ranges associated with the range interval; the results thus obtained serve to bracket the actual frequencies. Table 5-1 shows the frequency with which gunners were on target. The table indicates that gunner performance was good in the horizontal direction and appreciably worse in the vertical direction. Also, performance in the vertical direction is seen, strange as this may seem, to improve as range increases and apparent target size decreases.

It is of interest to indicate here to what extent the method used in these analyses to determine the standard deviation of various distributions affects calculated frequencies of the gunner being on target. Recall that the procedure adopted deemphasizes outliers at either end of the distribution, to minimize the effect of large errors that one might choose to exclude if they could be checked further and their basis understood. Frequencies corresponding to those in Table 5-1 were calculated from the standard deviation estimates, rather than obtained directly from the error data as was done to prepare the table. Calculated frequencies are plotted versus actual frequencies in Figure 5-11. The differences apparently never exceed about 10 percent of the values based directly on the implementation error data.

Table 5-1 shows that gunners were on target in the horizontal direction practically all the time. The target length (6.9 meters) was large enough that gunners apparently did not find it necessary to aim more carefully at longer ranges. The fact that frequencies of being on target are nearly 1.00 for this particular target does not prove that gunners aimed with the same degree of care at all ranges, however. The observed horizontal implementation errors tabulated in 5.3.4 for the various range intervals give the following estimates for the standard

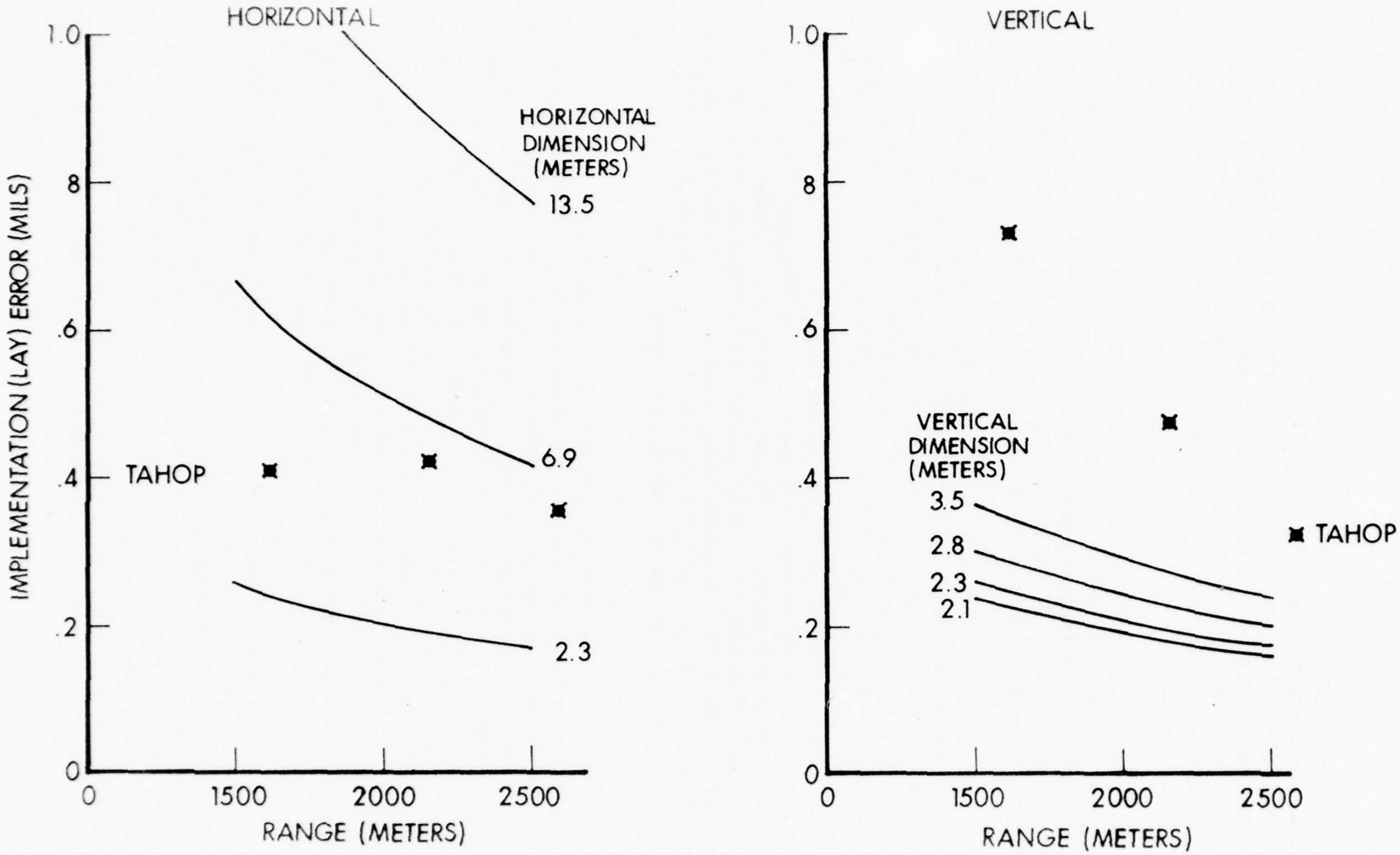

Figure 5-10. Comparison of TAHOP Implementation Errors and Lay Errors Expected According to Target Size.

TABLE 5-1 EFFECT OF IMPLEMENTATION ERRORS ON FREQUENCY OF GUNNER BEING ON HOVERING TARGET

TARGET DIMENSION (METERS)	FREQUENCY OF GUNNER BEING ON TARGET IN INDICATED DIRECTION VERSUS RANGE INTERVAL AND RANGE (METERS)					
	INTERVAL 1		INTERVAL 2		INTERVAL 3	
	1550	1700	2050	2250	2450	2700
			HORIZONTAL			
6.9 (BODY LENGTH)	.97	.97	.98	.97	.98	.98
13.5 (ENTIRE LENGTH)	1.00	.99	1.00	1.00	.99	.99
			VERTICAL			
2.1 (BODY)	.63	.55	.69	.63	.75	.73
2.8 (BODY AND COWLING)	.76	.71	.81	.77	.83	.80
3.5 (SKID TO CENTERLINE OF ROTOR)	.84	.84	.85	.83	.90	.85

TABLE 5-2 DISTRIBUTIONS OF HORIZONTAL IMPLEMENTATION ERRORS FOR THREE RANGE INTERVALS

RANGE (METERS)	SAMPLE SIZE	NUMBER (PERCENT) OF OBSERVED HORIZONTAL IMPLEMENTATION ERRORS LESS THAN OR EQUAL TO				
		0.2 MIL	0.4 MIL	0.6 MIL	0.8 MIL	1.0 MIL
UNDER 1900	78	26(33%)	49(63%)	61(78%)	67(86%)	69(89%)
1900-2400	89	38(43)	63(71)	70(79)	75(84)	77(87)
OVER 2400	81	39(48)	57(70)	65(80)	71(88)	78(96)

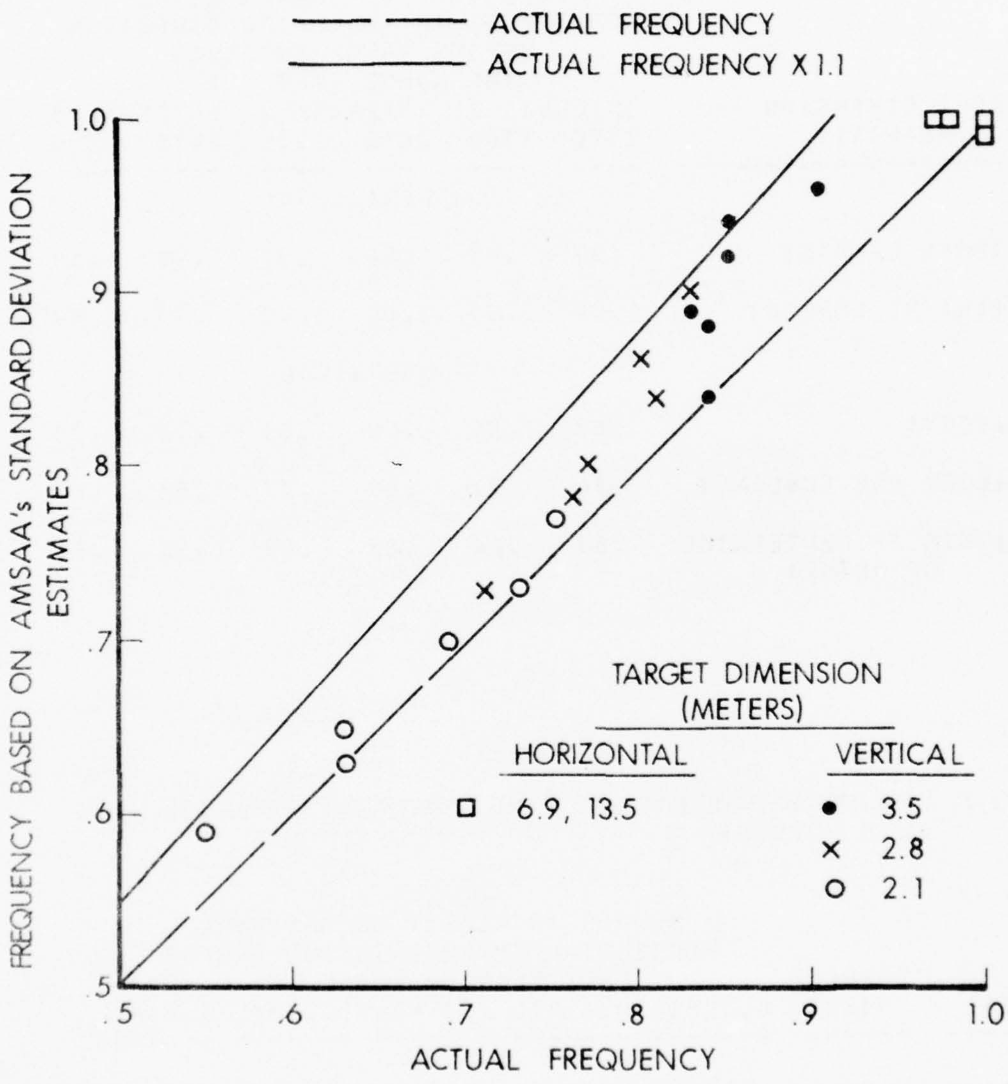

Figure 5-11 Effect of Deemphasizing Outlier Data on Estimated Frequency of Gunner Being on Target.

deviation:

a. 0.41 mil under 1900 meters.

b. 0.42 mil for 1900 through 2400 meters.

c. 0.36 mil over 2400 meters.

These standard deviations do not appear to depend appreciably on range. This was checked further, however. The distributions of horizontal implementation errors are more completely represented in Table 5-2, which indicates the number and percent of observed errors less than or equal to 0.2, 0.4, 0.6, 0.8, and 1.0 mil. The data for 0.2 and 0.4 mil show that, in some instances at least, gunners seem to have exercised noticeably greater care, when aiming in the horizontal direction, at the longer ranges than at the shortest ranges. This phenomenon is masked if only standard deviations, determined in the manner selected for these analyses, are available.

As can be seen from Table 5-1, the frequencies with which gunners aimed off target in the vertical direction are appreciable. The vertical implementation errors on which these frequencies are based are large, even as compared to the spacing on the ballistic reticle of approximately 1 mil per 400 meters. Furthermore, these errors have been compared to lay error estimates based on previous knowedge for ground targets fired at by tanks. When such vertical lay error estimates were made for targets having vertical dimensions like those of the AH-1G helicopter, the lay errors were found to be only 1/3 to 2/3 of the vertical implementation errors observed in TAHOP. No plausible reason explaining the performance of the TAHOP gunners has yet been surmised. One wonders how gunners could have acted as if they thought that aiming in the vertical direction required much less care than aiming in the horizontal direction. Also, gunner performance in the vertical direction improved as range increased, as is evident from Table 5-1, so one may ask why the performance achieved at the longest ranges was not duplicated, even if not improved upon, at other ranges.

All of these difficulties notwithstanding, one must decide whether to base hit probability calculations on the horizontal and vertical implementation errors actually observed in TAHOP or on some other (more appropriate) values. As has just been emphasized, it is not understood why gunners did better in the horizontal than in the vertical direction, in spite of the vertical dimension being smaller. The first decision made was to consider that, with proper training and opportunities to learn from live firing situations, gunners would be capable of doing at least as well vertically as TAHOP gunners did horizontally. The second decision was to adopt the standard formula normally used to represent lay errors against stationary ground targets and to modify the formula to account for the vertical dimensions of particular aerial targets. The modification consists of scaling

according to the target vertical dimension so that the gunner is, in effect, assumed to accept a cruder lay against a bigger target as long as he is always somewhere on target. Consequently, horizontal implementation errors and vertical implementation errors are each considered to have a mean value of zero and a standard deviation based on the modified lay error formulation. The standard formula for the 2.3 meter by 2.3 meter vertical target is as follows:

$$\text{Lay error} = 0.05 \text{ mil} + 0.3 \text{ meter}$$

The corresponding formula for any vertical target dimension is:

$$\text{Lay error} = 0.05 \text{ mil} + 0.3 \left(\frac{\text{Target Vertical Dimension (meters)}}{2.3 \text{ (meters)}}\right) \text{meter}$$

$$= 0.05 \text{ mil} + (0.13 \text{ Target Vertical Dimension (meters)})$$

which clearly agrees with the original standard formula for a target 2.3 meters high. Calculations are to be based on the vertical dimension of the helicopter body and cowling (2.8 meters in the case of the AH-1G).

More detailed information concerning the vertical errors and their components follows in Subsections 5.3.7 through 5.3.10.

5.3.7 Detailed Data Concerning Range Estimate Error.

Analysis of data for both the 248 firings associated with a zero lead estimate and the 130 firings in which gunners performed as instructed provided the following range estimate errors:

	RANGE ERROR (METERS)		
	-1 STD DEV	MEAN	+1 STD DEV
248 FIRINGS	-483.5	-138.1	+165.1
130 FIRINGS	-490.8	-149.9	+143.6

The possible dependence of the range estimate error on gunner was investigated. Related information for all 248 firings is as follows:

GUNNER (SAMPLE SIZE)	RANGE ERROR (METERS) -1 STD DEV	MEAN	+1 STD DEV
1 (25) *	-666.8	-252.9	-162.5
2 (28)	-239.3	+ 39.1	+336.5
4 (9) *	-152.6	+160.2	+433.5
5 (21)	- 49.6	+140.9	+310.6
7 (25) *	- 49.1	+131.8	+298.7
9 (29) *	-652.7	-208.1	-106.1
11 (16) *	-626.1	-142.2	-103.9
12 (21)	-970.0	-464.4	+154.3
13 (26) *	-318.4	-138.2	+ 89.3
14 (18)	-474.7	-154.7	-123.5
15 (8)	-288.9	-116.2	+144.7
16 (9)	-168.5	- 79.8	+345.2
17 (13)	-659.9	-440.9	-132.0

Asterisks identify gunners in the sample of 130 firings where super-elevation was consistently applied. In addition, because the gunner needs to interpolate on his reticle whenever his estimate does not correspond to a multiple of 400 or 200 meters, the tendency to round off range estimates to a multiple of either number was checked. (See Figure 2-1, which shows the M60A1 tank's M105D telescope's reticle pattern for APDS.) Results for all 248 firings are tabulated below:

ESTIMATED RANGE (METERS)	RANGE ERROR (METERS) -1 STD DEV	MEAN	+1 STD DEV
MULTIPLE OF 400 (AND 200)	-602.3	-154.6	+179.2
MULTIPLE OF 200 BUT NOT 400	-318.2	+ 89.3	+433.7
NOT MULTIPLE OF 200 (OR 400)	-437.6	-141.8	+ 53.0

No obvious relationship emerged. The relationship between range estimate error, in mils, and range, for both all 248 firings and 130 selected firings, is shown in the following tabulation:

RANGE (METERS)	RANGE ERROR (MILS) -1 STD DEV	MEAN	+1 STD DEV
		248 FIRINGS	
UNDER 1900	-0.40	-0.13	+0.78
1900 THROUGH 2400	-1.18	-0.39	+0.56
OVER 2400	-1.84	-0.72	-0.13
		130 FIRINGS	
UNDER 1900	-0.43	-0.26	+0.44
1900 THROUGH 2400	-1.03	-0.40	+0.43
OVER 2400	-1.79	-1.02	+0.24

Data for 248 and 130 firings do not seem appreciably different. The remainder of this discussion is based on the data for the 248 firings.

As a basis for hit probability calculations, the following determinations were made:

a. A representative range was chosen for each interval. These ranges and the superelevation needed for targets at such ranges are as follows:

RANGE (METERS)	REPRESENTATIVE RANGE (METERS)	SUPERELEVATION (MILS)
UNDER 1900	1500	3.92
1900 THROUGH 2400	2000	5.22
OVER 2400	2500	6.53

b. The means and standard deviations were divided by the corresponding superelevations to express range error as a percent of the range. The results of this calculation were:

	RANGE ERROR			
	MILS		PERCENT OF RANGE	
RANGE (METERS)	MEAN	STD DEV	MEAN	STD DEV
UNDER 1900	-0.13	0.59	- 3	15
1900 THROUGH 2400	-0.39	0.87	- 7	17
OVER 2400	-0.72	0.86	-11	13

c. The range estimate error is considered to have a mean value of zero at all ranges. The negative biases, corresponding to frequent underestimation of ranges, may be real, though 4 of 13 gunners exhibited positive biases, corresponding to overestimation of ranges.

d. The results of the TAHOP experiment do not form a basis for rejecting the zero mean, 17 percent standard deviation previously

used for describing the capability of tank gunners using stadia range finders.

5.3.8 Detailed Data Concerning Vertical Lead Estimate Error.

Analysis of data for the 130 firings associated with a zero lead estimate and gunner performance in accordance with instructions yielded the following results:

	VERTICAL LEAD ERROR		
	-1 STD DEV	MEAN	+1 STD DEV
KNOTS	-1.88	-0.28	+1.32
MILS	-0.63	-0.09	+0.44

The possible dependence of the lead estimate error in knots on range and gunner was also investigated. Related information is as follows:

	VERTICAL LEAD ERROR (KNOTS)		
RANGE (METERS)	-1 STD DEV	MEAN	+1 STD DEV
UNDER 1900	-2.43	+0.14	+1.84
1900 THROUGH 2400	-1.20	+0.32	+2.46
OVER 2400	-1.24	+0.24	+1.77
GUNNER (SAMPLE SIZE)			
1 (25)	-1.20	+0.21	+1.40
4 (9)	-2.23	+0.39	+4.17
7 (25)	-0.95	+0.25	+2.43
9 (29)	-1.05	+0.72	+2.08
11 (16)	-3.67	-0.81	+1.11
13 (26)	-1.32	+0.16	+1.78

The relationship between lead estimate error in knots and situations where the estimated range is a multiple of 400 or 200 meters is indicated below:

ESTIMATED RANGE	VERTICAL LEAD ERROR (KNOTS)		
(METERS)	-1 STD DEV	MEAN	+1 STD DEV
MULTIPLE OF 400 (AND 200)	-2.43	+0.06	+1.90
MULTIPLE OF 200 BUT NOT 400	-1.13	+0.39	+2.06
NOT MULTIPLE OF 200 (OR 400)	-1.36	+0.50	+2.04

No apparent relationship emerged.

5.3.9 Detailed Data Concerning Vertical Implementation Error.

Basic data for the 130 selected firings were analyzed according to two alternative assumptions for interpreting signs:

a. An above or below (A/B) case where a positive error means the round would have passed above, and a negative error below, the aim point.

b. An overlead or underlead (O/U) case where a positive error means the round would have passed above, and a negative error below, an aircraft moving upward, and where a positive error means the round would have passed below, and a negative error above, an aircraft moving in the downward direction.

Standard deviation would be reduced for the overlead or underlead convention compared to the above or below convention if gunner tended to apply lead in the direction of motion of the target. Results for the two cases follow:

	VERTICAL IMPLEMENTATION ERROR (MILS)		
	-1 STD DEV	MEAN	+1 STD DEV
ABOVE OR BELOW (A/B)	-0.52	+0.06	+0.54
OVERLEAD OR UNDERLEAD (O/U)	-0.52	+0.02	+0.57

The possible dependence of the implementation error for the above or below case on range, gunner, and target vertical velocity, and target horizontal velocity was also studied. Results are shown in the following tabulations:

	VERTICAL IMPLEMENTATION ERROR,A/B (MILS)		
RANGE (METERS)	-1 STD DEV	MEAN	+1 STD DEV
UNDER 1900	-0.88	+0.17	+0.62
1900 THROUGH 2400	-0.48	0.00	+0.50
OVER 2400	-0.32	+0.04	+0.37

GUNNER (SAMPLE SIZE)			
1 (25)	-0.37	-0.04	+0.35
4 (9)	-0.35	+0.14	+0.66
7 (25)	-0.34	+0.23	+0.77
9 (29)	-0.18	+0.10	+0.54
11 (16)	-0.88	-0.03	+0.57
13 (26)	-1.17	-0.30	+0.21
VERTICAL VELOCITY (KNOTS)			
UNDER 1.0	-0.58	-0.14	+0.57
1.0 THROUGH 2.0	-0.23	+0.01	+0.37
OVER 2.0	-0.62	-0.14	+0.78
HORIZONTAL VELOCITY (KNOTS)			
UNDER 1.5	-0.50	+0.01	+0.57
1.5 THROUGH 3.0	-0.62	-0.15	+0.48
OVER 3.0	-0.49	-0.14	+0.60

The relationship between implementation error for the above or below case and situations where the estimated range is a multiple of 400 or 200 meters is indicated below:

ESTIMATED RANGE (METERS)	VERTICAL IMPLEMENTATION ERROR,A/B (MILS) -1 STD DEV	MEAN	+1 STD DEV
MULTIPLE OF 400 (AND 200)	-0.37	+0.14	+0.54
MULTIPLE OF 200 BUT NOT 400	-1.03	-0.01	+0.37
NOT MULTIPLE OF 200 (OR 400)	-0.72	-0.07	+0.57

No obvious relationship emerged.

5.3.10 Detailed Data Concerning Vertical Error.

The vertical total error was determined, for the 130 selected firings and both assumptions, to be as follows:

	VERTICAL ERROR (MILS)		
	-1 STD DEV	MEAN	+1 STD DEV
ABOVE OR BELOW (A/B)	-1.68	-0.49	+0.59
OVERLEAD OR UNDERLEAD (O/U)	-1.73	-0.62	+0.42

5.3.11 Distributions Of Velocity Estimates.

The distributions of velocity estimates, as a function of horizontal crossing velocity, are of interest, partly for purposes of comparison with similar information based on Constant Speed Level maneuver data discussed in Subsection 5.4. Exceptionally, these distributions are based on the 281 firing events previously mentioned, rather than on any subset. Velocity estimates are distributed as follows:

VELOCITY ESTIMATE (KNOTS)	PERCENT OF SAMPLE SIZE CORRESPONDING TO HORIZONTAL CROSSING VELOCITY INTERVAL 1 THROUGH 6 WITH INDICATED VELOCITY ESTIMATE 1*	2	3	4	5	6
0	94	96	90	92	88	58
2	0	0	2	2	2	0
3	0	0	0	0	10	7
5	6	2	8	6		35
10		2				

* INTERVALS AND SAMPLE SIZES ARE AS FOLLOWS

INTERVAL	HORIZONTAL CROSSING VELOCITY (KNOTS)	SAMPLE SIZE
1	0 THROUGH 0.57	50
2	0.57+ THROUGH 1.24	50
3	1.24+ THROUGH 1.84	50
4	1.84+ THROUGH 2.60	50
5	2.60+ THROUGH 3.67	50
6	3.67+ THROUGH 7.36	31

Blanks represent zeros in this tabulation. Note the high frequencies with which zero estimates appear for most of the horizontal crossing velocities.

5.4 Constant Speed Level Flight.

5.4.1 Introduction.

This subsection covers various analyses of basic TAHOP data related to the Constant Speed Level maneuver situations. Throughout Subsection 5.2 errors were treated at any one time as a function of only one independent variable, either range or velocity, for each of the maneuver categories considered. Such an approach might neglect interactive effects in the event the errors are functions of more than one variable. Because performance of the gunners was expected to be dependent on both range and velocity (and, in this maneuver, velocity is not negligible), a two variable approach was applied. Both velocity/range and velocity/background interactions were investigated.

5.4.2 Velocity/Range Interactions.

The initial examination of the TAHOP data, which resulted in Figures 5-12 through 5-16, failed to show any discernible effect of range. Figures 5-12 through 5-15 show horizontal and vertical errors and horizontal and vertical implementation errors as a function of horizontal or vertical crossing velocities, with range as a parameter. Figure 5-16 shows the velocity estimate error versus the combined horizontal and vertical crossing velocities (dominated at large values by the horizontal crossing velocities) with range as a parameter.

5.4.3 Velocity/Background Effects.

Figures 5-17 through 5-21 differ from Figures 5-12 through 5-16 only in that background is the parameter, rather than range. The three background levels identified are:

a. Terrain - Terrain behind helicopter at simulated fire time.

b. Sky Behind Target/Horizon In View - Sky behind target with some terrain visible in gun camera film at the simulated fire time.

c. Sky Only - No terrain visible in gun camera film at simulated fire time. (Terrain was always in the field of view of the gunner's sight except possibly during some of the evasive maneuvers when the range was less than 1500 meters.)

It appears there may be some background effects, but they are not substantial enough to quantify on the basis of the data presented in Figures 5-17 through 5-21. A more thorough examination of the data is required if the dependence of gunner performance on range and background is to be quantified. The following subsection (5.4.4) initiates a more substantial examination of this portion of the TAHOP data.

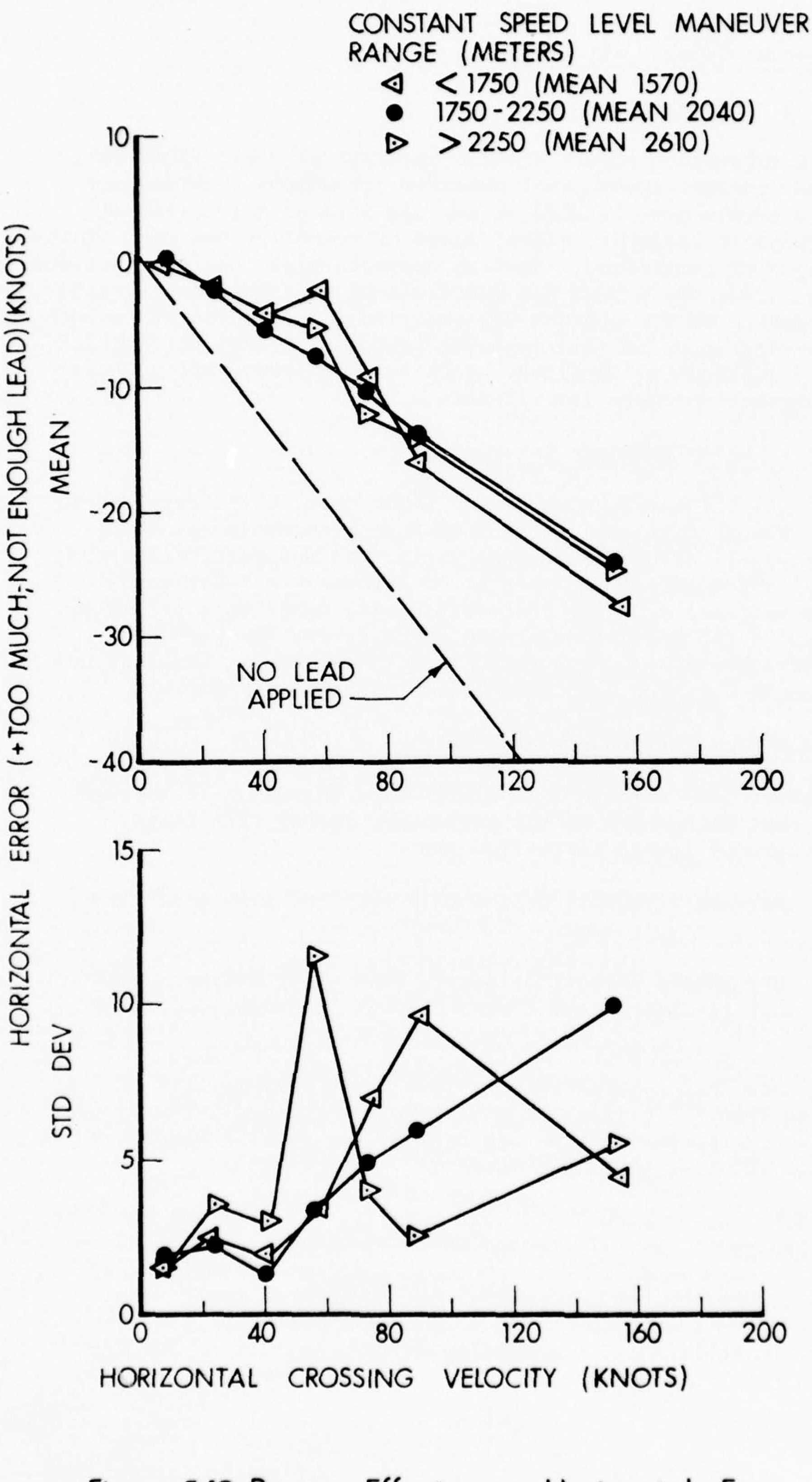

Figure 5-12. Range Effects on Horizontal Error.

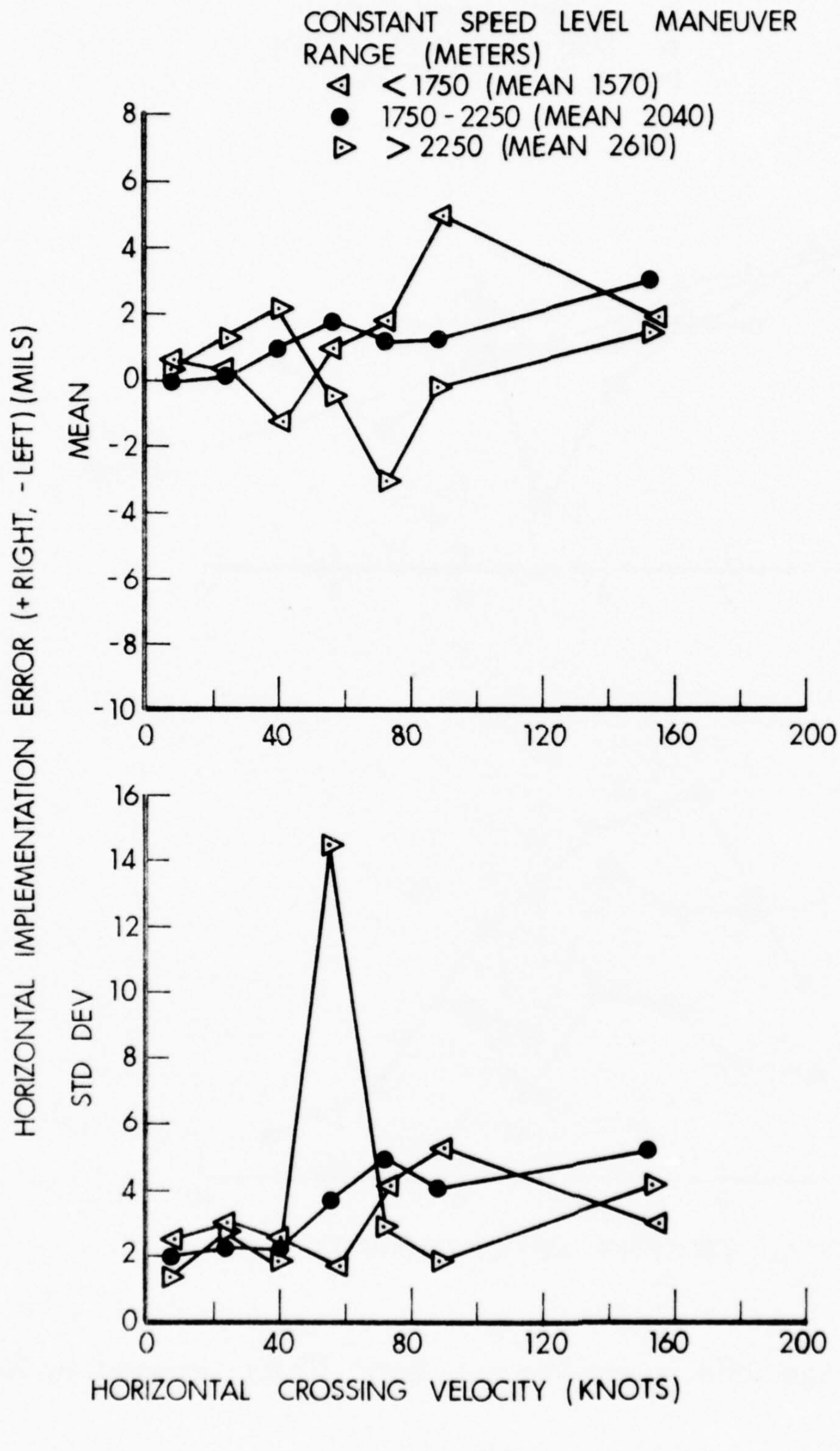

Figure 5-13. Range Effects on Horizontal Implementation Error.

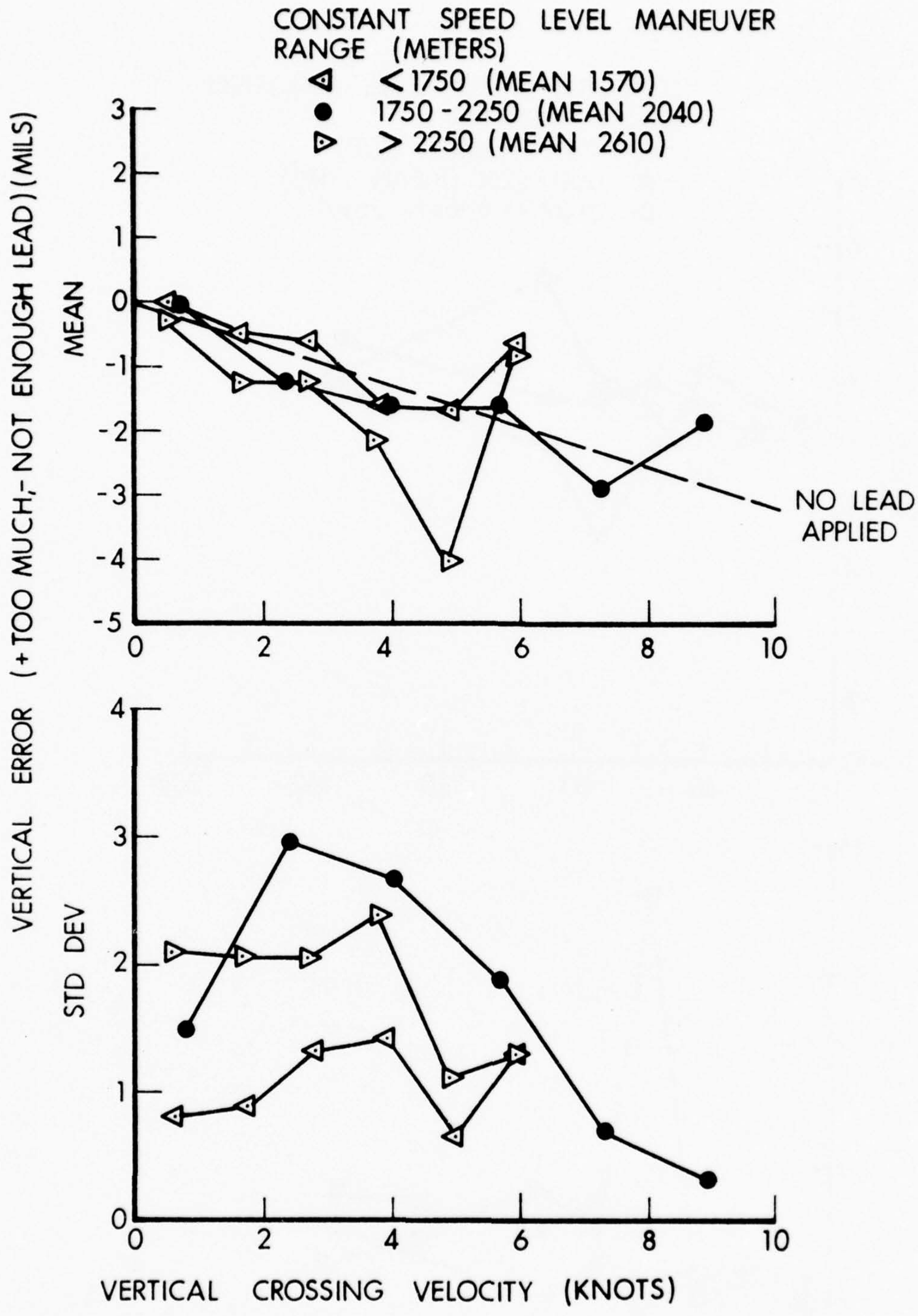

Figure 5-14. Range Effects on Vertical Error (Data Grouped by Range).

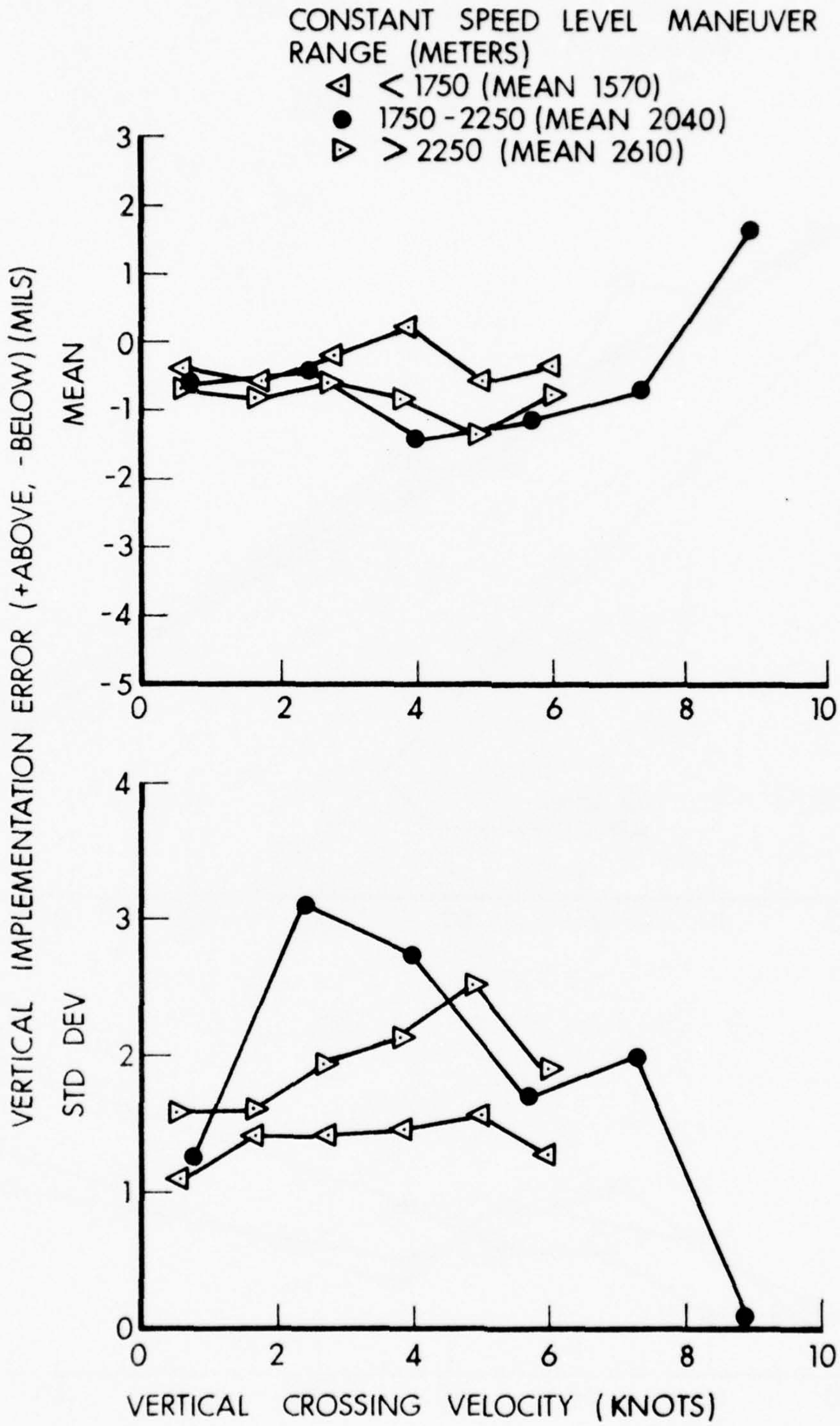

Figure 5-15. Range Effects on Vertical Implementation Error.

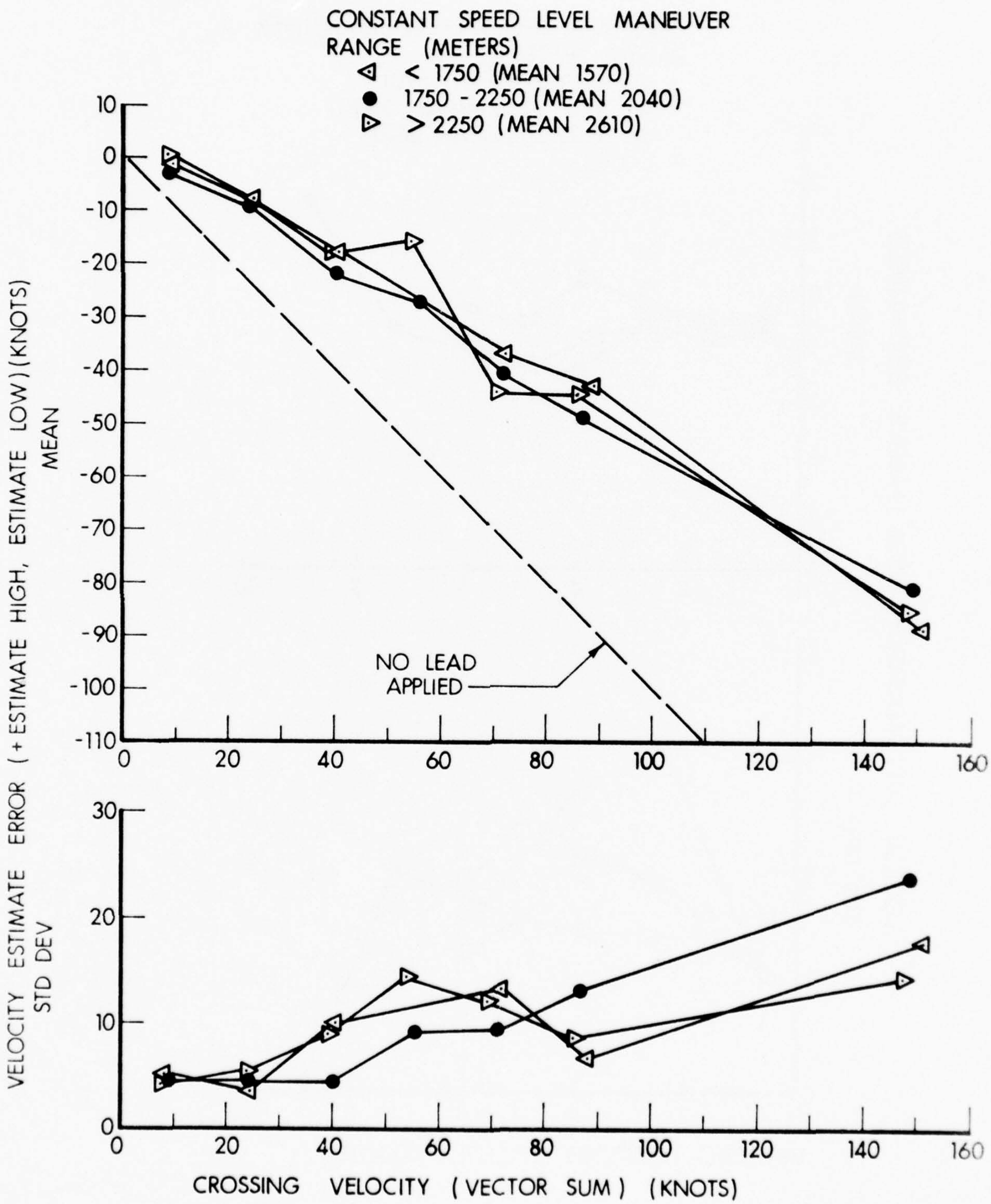

Figure 5-16. Range Effects on Velocity Estimate Error.

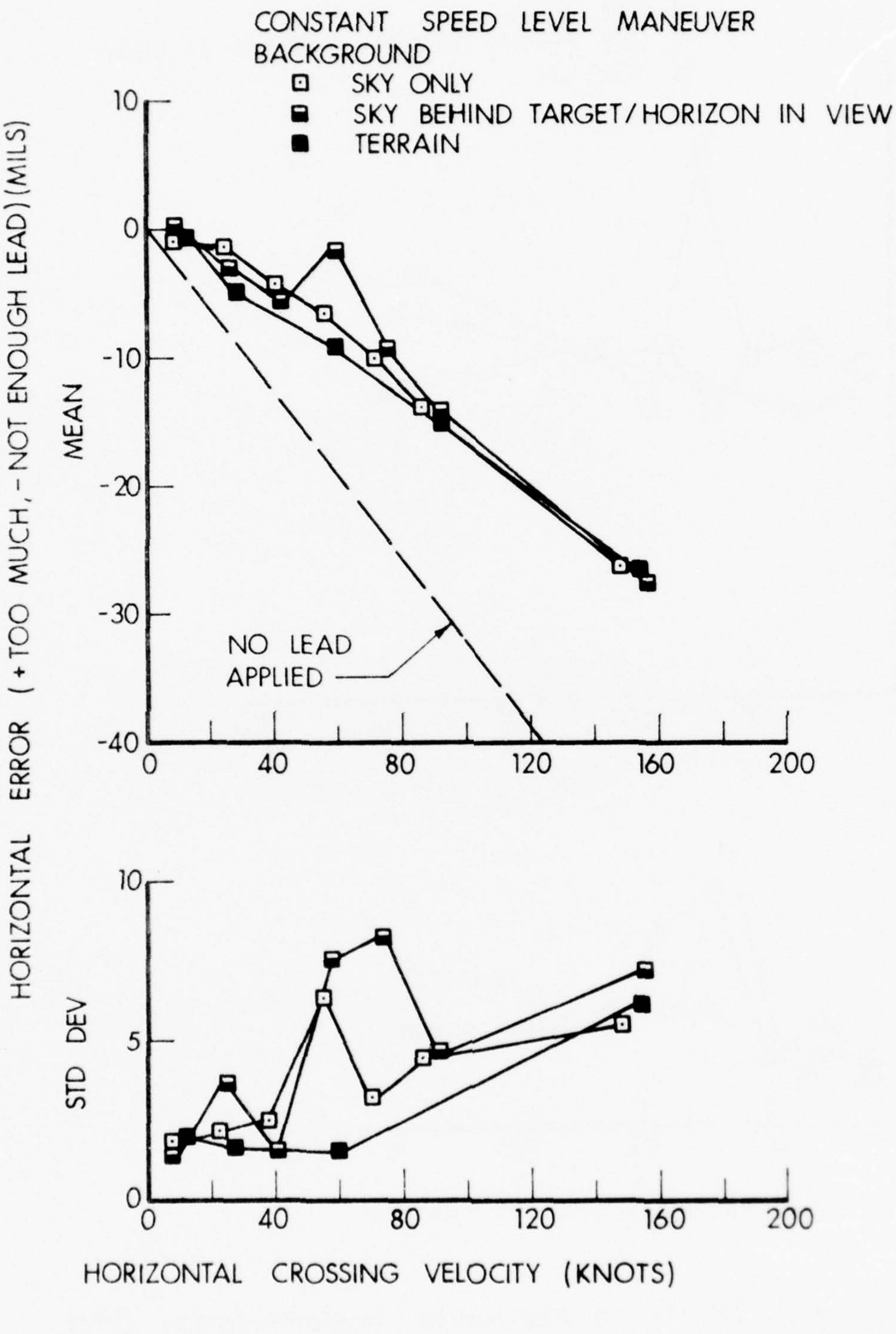

Figure 5-17. Background Effects on Horizontal Error.

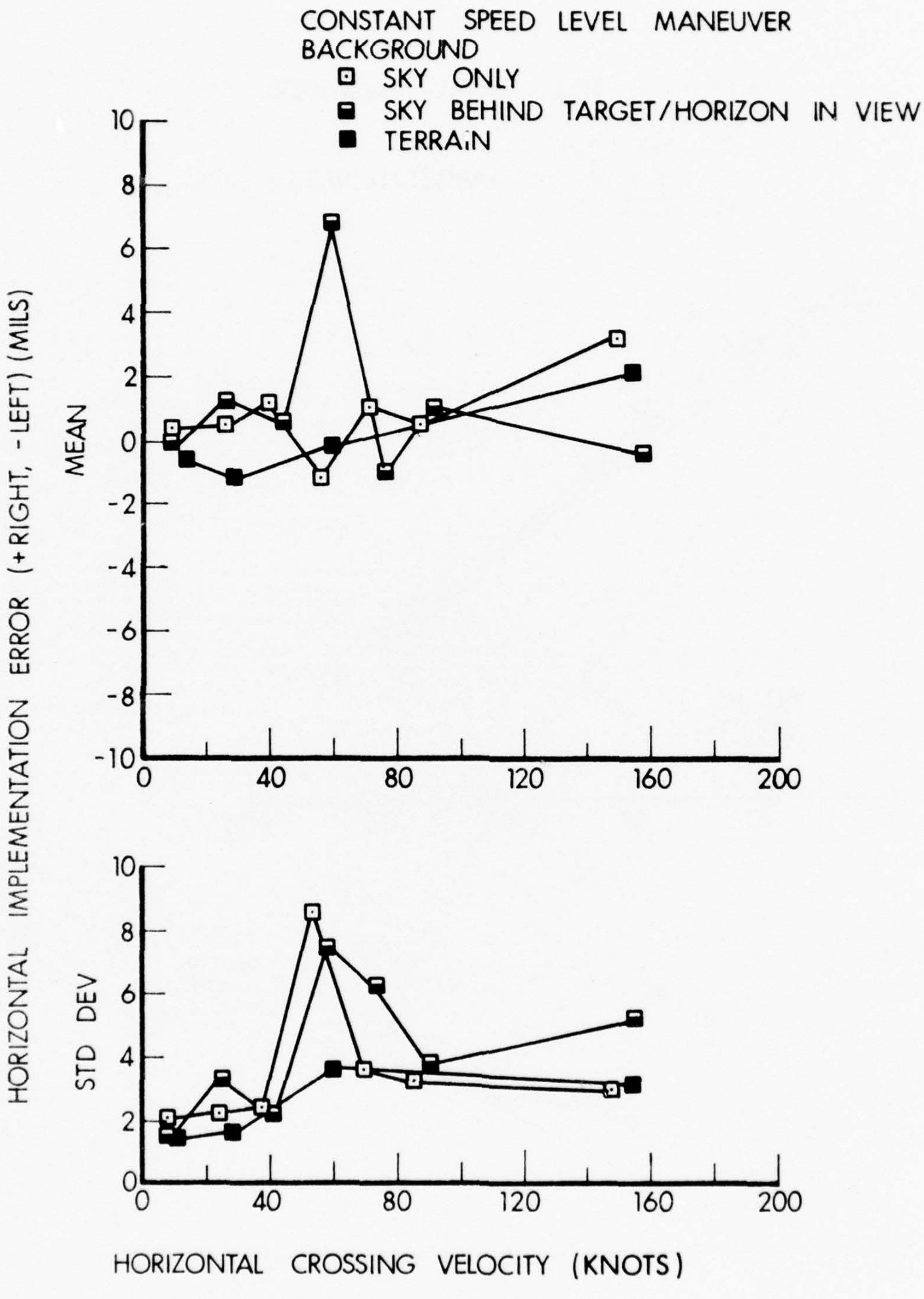

Figure 5-18. Background Effects on Horizontal Implementation Error.

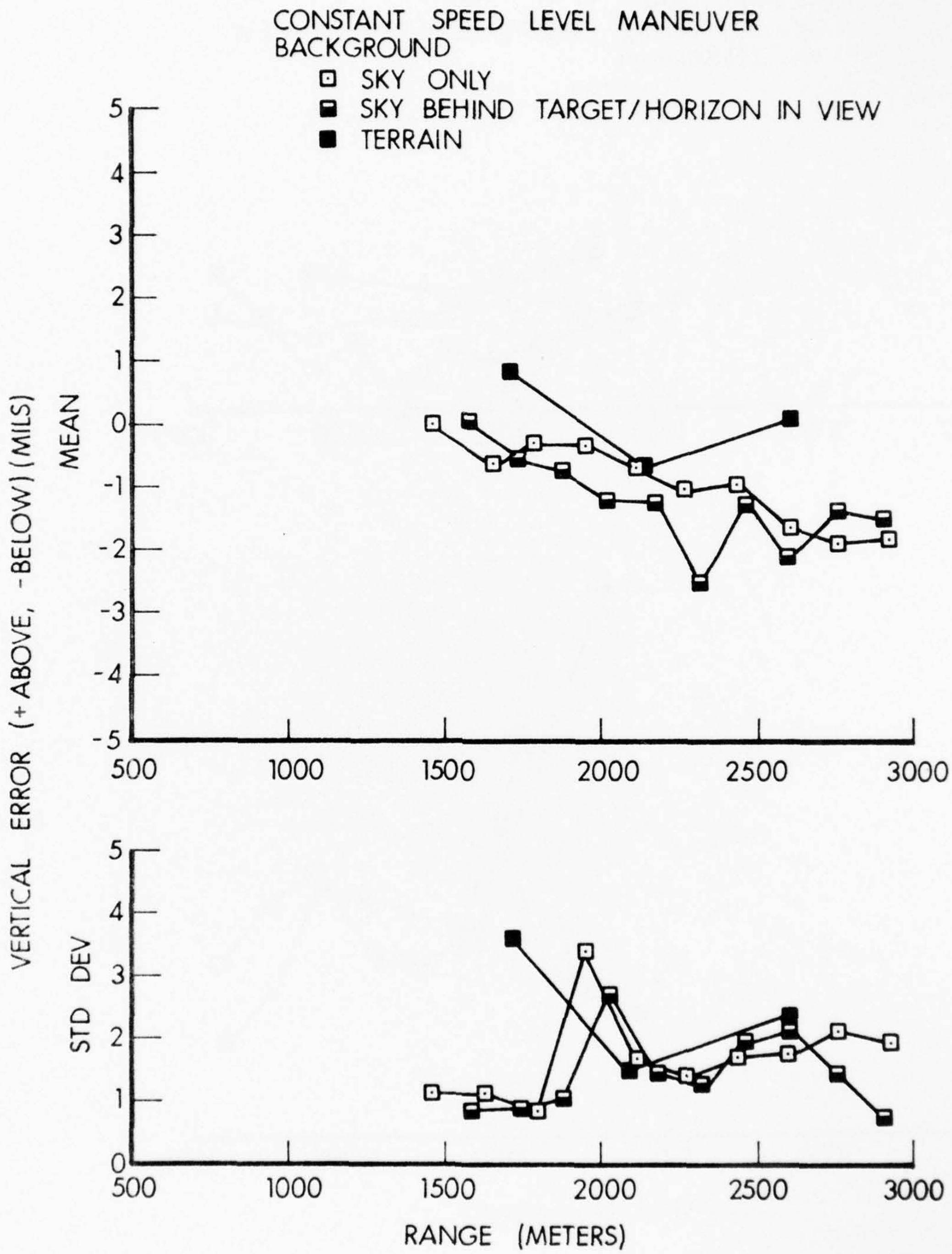

Figure 5-19. Background Effects on Vertical Error

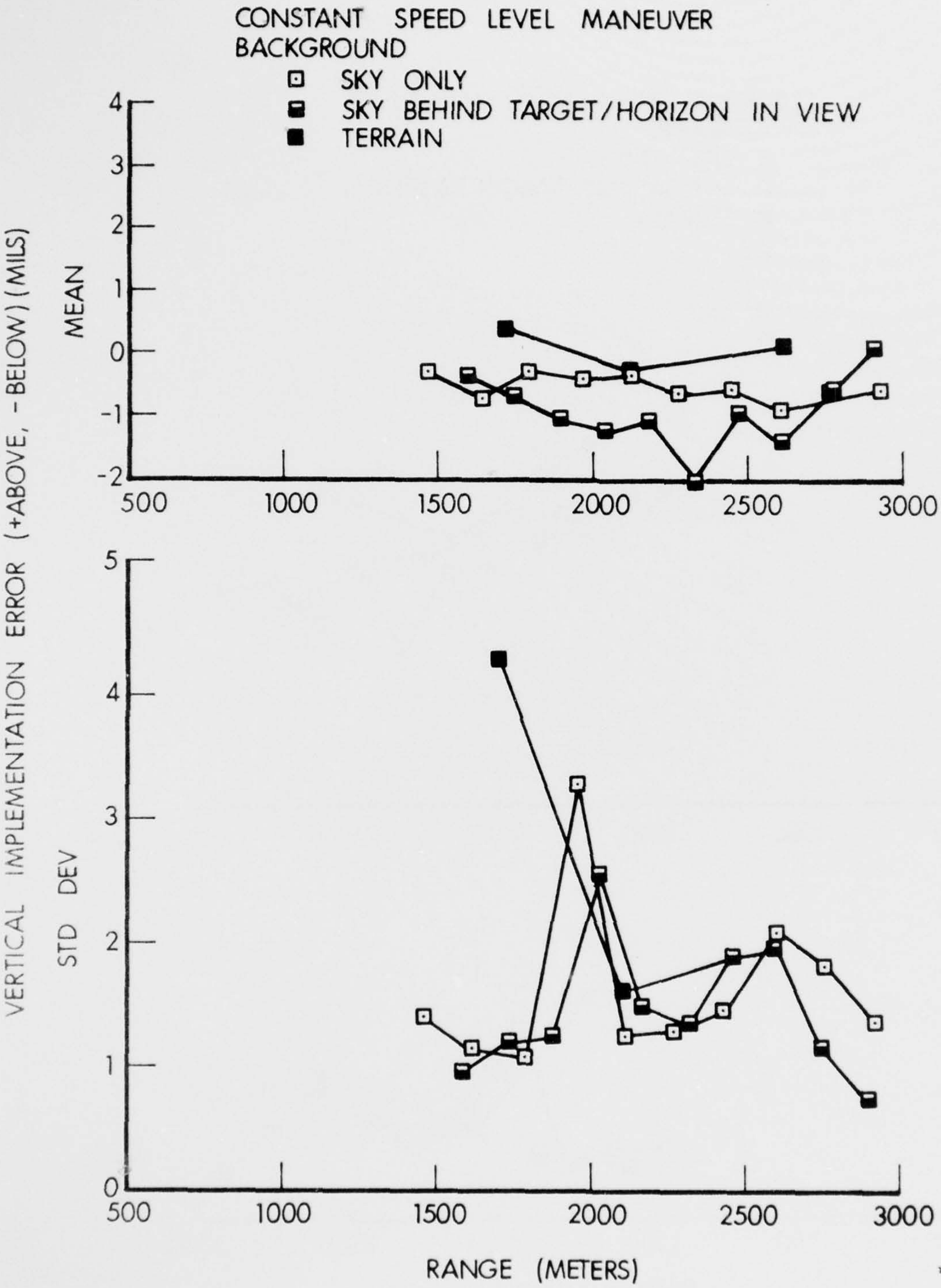

Figure 5-20. Background Effects on Vertical Implementation Error.

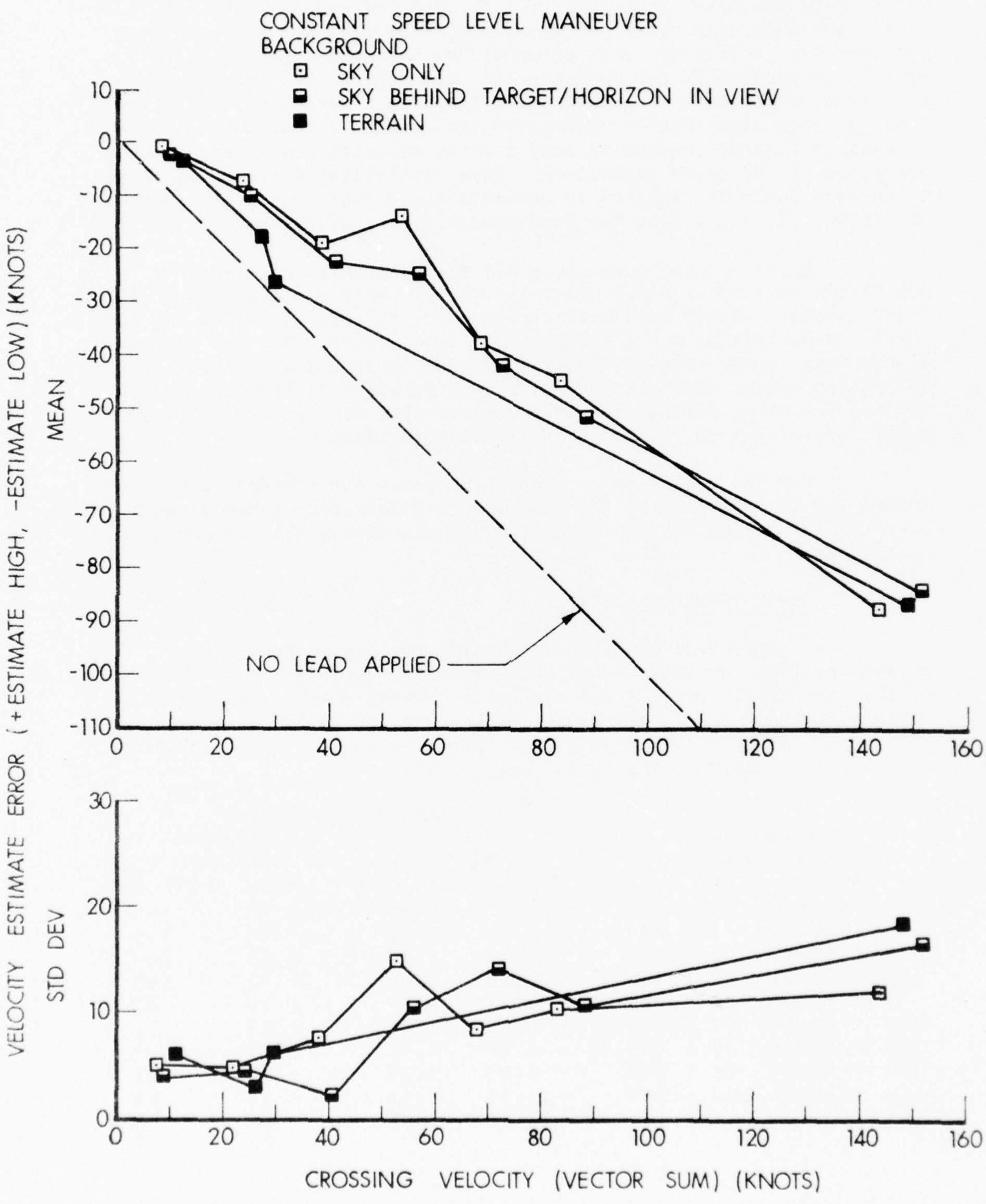

Figure 5-21. Background Effects on Velocity Estimate Error.

5.4.4 Second Phase Analyses.

Subsequent to the initial analysis of the Constant Speed Level flight data presented in Figures 5-1 through 5-8 and 5-12 through 5-21, a more thorough examination of the basic TAHOP data for this maneuver category was initiated. This examination, which was quite limited in extent, is covered by the remainder of this subsection. Because of the strong dependence of gunner performance on crossing velocity, and a non-uniform distribution of crossing velocities throughout the other parameters (and/or inadequate sample sizes associated with many such groupings of the other parameters), more sophisticated procedures than those used would be required to separate the effects of range, approach direction, etc . . . from the fundamental effect of crossing velocity.

Basic reduced data cover 871 firing events in which the target helicopter pilot was instructed to maintain a constant speed level course. Usable data were obtained for 847 events. (The 849 data points in Subsection 5.4.8 reflect work done earlier; the two data point discrepancy is not readily identifiable and is inconsequential.) Only 438 firing events were considered for the analyses of vertical errors, because the other firings involved gunners that did not consistently apply superelevation related to their range estimate.

For the same reasons as before, means and standard deviations needed for this portion of the effort were determined by applying the non-standard methods already explained in connection with the Hover situations.

5.4.5 Horizontal Errors.

A sufficient basis for examining the components (i.e., horizontal lead estimate errors and horizontal implementation errors) of the horizontal error is not available. Parameters describing the distributions of total horizontal errors observed in 847 firings constituting the selected data base are presented below as a function of the horizontal velocity of the target helicopter:

HORIZONTAL VELOCITY (KNOTS) (SAMPLE SIZE)		HORIZONTAL ERROR MILS MEAN	STD DEV	PERCENT OF REQUIRED LEAD MEAN	STD DEV
0+ THROUGH 1	(20)	- 0.44	0.69	-264	414
1+ THROUGH 2	(29)	- 0.32	1.10	- 64	220
2+ THROUGH 5	(92)	- 0.60	1.65	- 51	141
5+ THROUGH 10	(152)	+ 0.25	1.57	+ 10	63
10+ THROUGH 20	(202)	- 0.69	1.90	- 14	38
20+ THROUGH 30	(81)	- 2.28	2.71	- 27	33
30+ THROUGH 60	(85)	- 5.54	3.18	- 37	21
60+ THROUGH 100	(154)	-13.73	6.12	- 51	23
OVER 100	(32)	-28.82	7.51	- 58	15

The preceding horizontal errors are referenced to the horizontal crossing velocity of the target and indicate that the round would have passed in front of the aircraft for positive errors and behind for negative errors. Horizontal errors, expressed as percents of the required lead, are plotted versus horizontal velocity in Figure 5-22; most of the data for horizontal velocities greater than 100 knots were for 140 to 160 knots and the associated mean and standard deviation were consequently made to correspond to a horizontal scale value of 150 knots.

The preceding standard deviations in mils are based on the following tabulation:

HORIZONTAL VELOCITY (KNOTS) (SAMPLE SIZE)	HORIZONTAL ERROR (MILS) -1 STD DEV	MEAN	+1 STD DEV
0+ THROUGH 1 (20)	- 1.12	- C.44	+ C.25
1+ THROUGH 2 (29)	- 0.97	- C.32	+ 1.22
2+ THROUGH 5 (92)	- 1.43	- 0.60	+ 1.87
5+ THROUGH 1C (152)	- 1.46	+ 0.25	+ 1.67
10+ THROUGH 2C (202)	- 2.36	- 0.69	+ 1.44
20+ THROUGH 3C (81)	- 5.21	- 2.28	+ C.21
30+ THROUGH 6C (85)	- 8.96	- 5.54	- 2.61
60+ THROUGH 1CC (154)	-20.76	-13.73	- 8.53
OVER 10C (32)	-35.42	-28.82	-2C.41

For horizontal crossing speeds above 30 knots, a mean error of -50 percent of the required lead and variability (standard deviation) of 20 percent of the required lead seem to fit the data. The values for horizontal crossing speeds below 30 knots are not sufficiently well-behaved, given the problems associated with the basic data, to make any reasonable estimates of the horizontal errors.

In the application of TAHOP emerging results referred to in Section 5.3.2, an alternative to the above was also evaluated. The reason is that the 50 percent bias causes relatively poor performance and is not considered a necessary characteristic of tank fire at moving helicopters. If the gunners had been instructed to use 2/3 mil per knot instead of 1/3 mil, the results would probably have had small biases but the dispersions would have been expected to increase from 20 percent to 40 percent of the required lead. A similar result would be expected from experience if gunners were trained with live ammunition that they could sense. Since doubling of the lead to be applied would enhance performance and is so easily implemented (and since this or an equivalent way of compensating for the bias would be quickly learned with live fire training), this modified procedure is considered to best represent the capability of the tanker. Thus, when estimating hit probability, zero mean and 40 percent standard deviation will be used.

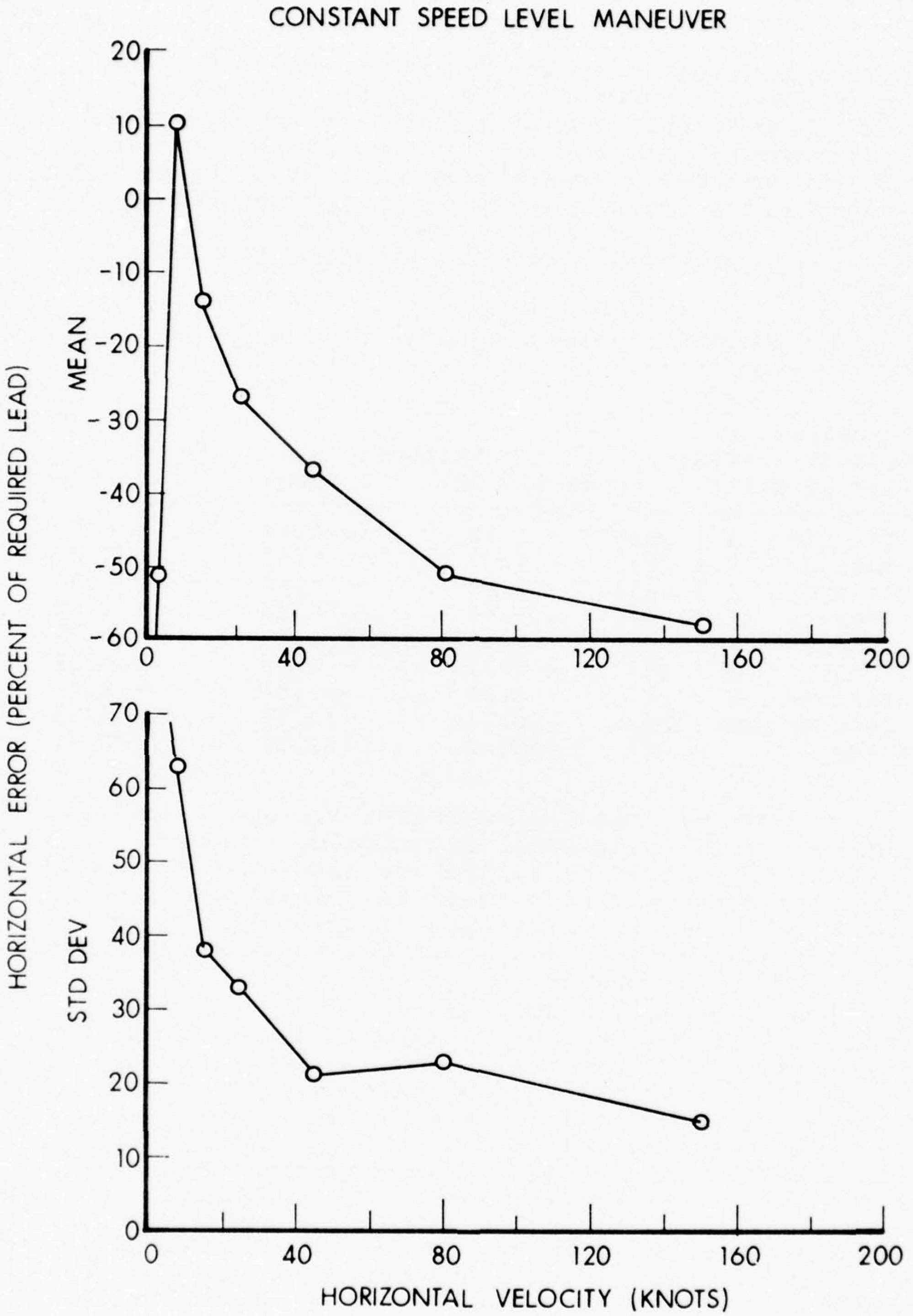

Figure 5-22. Horizontal Error vs Horizontal Velocity.

5.4.6 Vertical Errors.

As previously mentioned, the data base for analyzing vertical errors is 438 firings rather than 847. The overall characterization of the vertical implementation errors and vertical total range/lead/lay errors in the sample with 438 firings is presented below as a function of target horizontal velocity:

HORIZONTAL VELOCITY (KNOTS) (SAMPLE SIZE)		VERTICAL IMPLEMENTATION ERROR (MILS)		VERTICAL ERROR (MILS)	
		MEAN	STD DEV	MEAN	STD DEV
0+ THROUGH 1	(10)	-0.20	1.02	-0.42	1.73
1+ THROUGH 2	(13)	+0.44	0.89	-0.86	1.19
2+ THROUGH 5	(48)	-0.02	0.56	-0.84	1.22
5+ THROUGH 10	(63)	-0.12	0.55	-0.39	1.41
10+ THROUGH 20	(114)	-0.13	0.51	-0.51	1.42
20+ THROUGH 30	(48)	-0.24	0.71	+0.04	1.12
30+ THROUGH 60	(42)	+0.05	0.50	-0.44	1.33
60+ THROUGH 100	(83)	-0.23	0.85	-0.51	1.43
OVER 100	(17)	+0.22	1.34	+0.84	1.88
AGGREGATED	(438)	-0.08	0.69	-0.42	1.38

The preceding vertical errors are referenced to the coordinate system and indicate that the round would have passed above the target for positive errors and below for negative errors. The vertical errors are plotted versus horizontal velocity in Figure 5-23. There is no apparent pattern to either the vertical errors or the vertical implementation errors examined as a function of horizontal crossing velocity.

The observed vertical implementation errors and vertical errors for the aggregated data agree with corresponding data for the Hover situations. The tabulation below contains the Hover data from 5.3.6 and, in parentheses, corresponding values for the Constant Speed Level maneuver firing events.

	MEAN (MILS)	STD DEV (MILS)
OBSERVED VERTICAL ERRORS	-0.49(-0.42)	1.14(1.38)
OBSERVED RANGE ESTIMATE ERRORS	-0.39	0.83
OBSERVED LEAD ESTIMATE ERRORS	-0.09	0.53
OBSERVED IMPLEMENTATION ERRORS	+0.06(-0.08)	0.53(0.69)
COMBINED RANGE ESTIMATE, LEAD ESTIMATE, AND IMPLEMENTATION ERRORS	-0.42	1.12

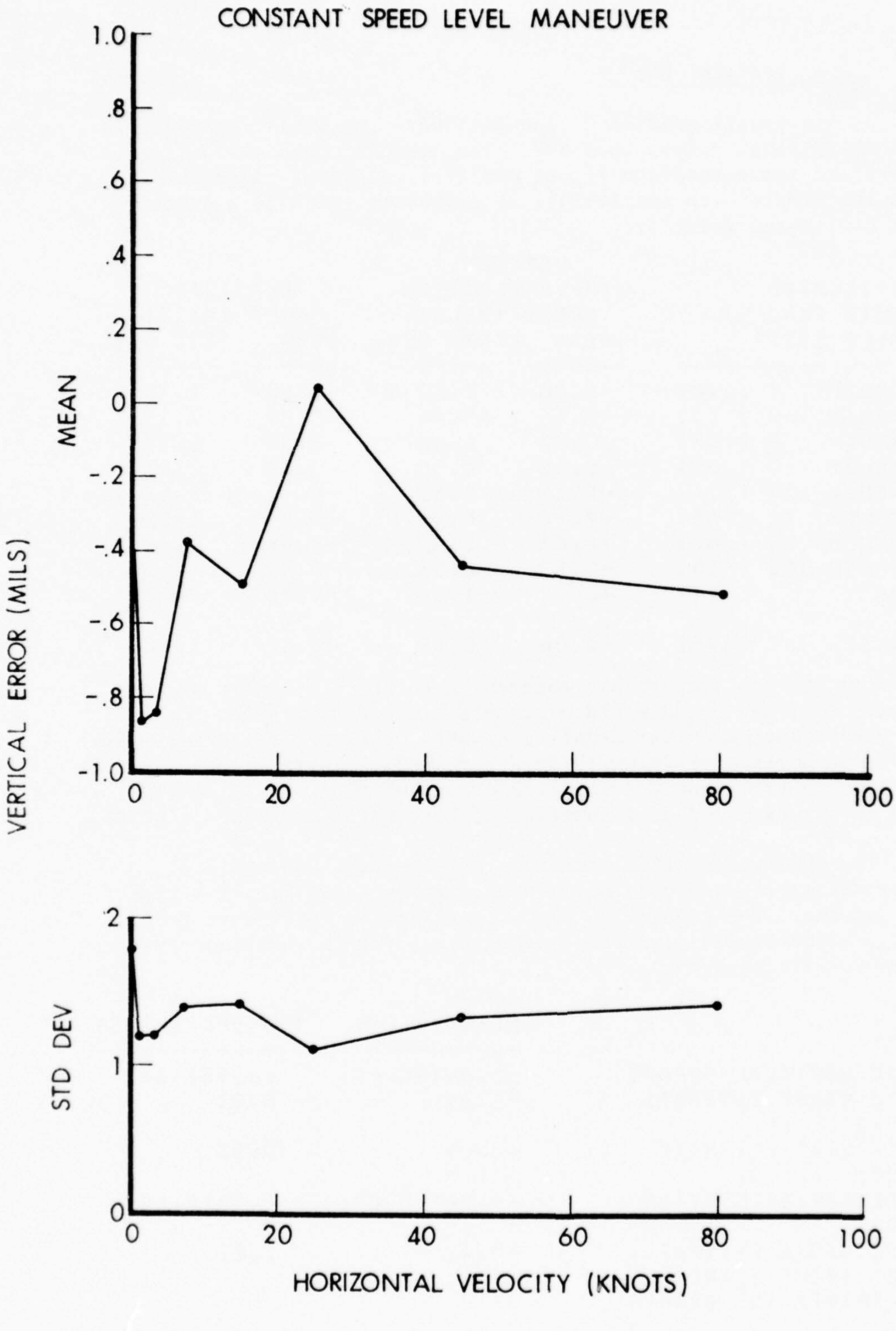

Figure 5-23. Vertical Error vs Horizontal Velocity.

In view of the agreement between the data for the Constant Speed Level and Hover situations, it is concluded that, for hitting probability estimation purposes, the vertical errors specified for the Hover situations should also be used for the Constant Speed Level situations.

Detailed tabulations of vertical implementation errors and vertical errors as a function of the horizontal velocity of the target are as follows:

HORIZONTAL VELOCITY (KNOTS) (SAMPLE SIZE)	VERTICAL IMPLEMENTATION ERROR (MILS) -1 STD DEV	MEAN	+1 STD DEV
0+ THROUGH 1 (10)	-1.38	-0.20	+0.65
1+ THROUGH 2 (13)	-0.81	+0.44	+0.96
2+ THROUGH 5 (48)	-0.75	-0.02	+0.37
5+ THROUGH 10 (63)	-0.68	-0.12	+0.42
10+ THROUGH 20 (114)	-0.64	-0.13	+0.37
20+ THROUGH 30 (48)	-1.03	-0.24	+0.38
30+ THROUGH 60 (42)	-0.53	+0.05	+0.46
60+ THROUGH 100 (83)	-1.10	-0.23	+0.60
OVER 100 (17)	-0.85	+0.22	+1.82

HORIZONTAL VELOCITY (KNOTS) (SAMPLE SIZE)	VERTICAL ERROR (MILS) -1 STD DEV	MEAN	+1 STD DEV
0+ THROUGH 1 (10)	-2.18	-0.42	+1.27
1+ THROUGH 2 (13)	-2.36	-0.86	+0.02
2+ THROUGH 5 (48)	-2.00	-0.84	+0.43
5+ THROUGH 10 (63)	-2.27	-0.39	+0.54
10+ THROUGH 20 (114)	-1.89	-0.51	+0.94
20+ THROUGH 30 (48)	-1.72	+0.04	+0.52
30+ THROUGH 60 (42)	-1.89	-0.44	+0.76
60+ THROUGH 100 (83)	-2.31	-0.51	+0.54
OVER 100 (17)	-0.71	+0.84	+3.05

5.4.7 Distributions of Of Velocity Estimates.

Distributions of velocity estimates, as a function of the horizontal crossing velocity of the target, have been presented in 5.3.11 for the Hover situations. Similar information based on the Constant Speed Level maneuver firing events is as follows:

VELOCITY ESTIMATE (KNOTS)	PERCENT OF SAMPLE SIZE CORRESPONDING TO HORIZONTAL CROSSING VELOCITY INTERVAL 1 THROUGH 17 WITH INDICATED VELOCITY ESTIMATE																
	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	54	56	22	6	4	0	4	0	0	0	0	0	0	0	0	0	0
2	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
3	2	0	4	4	12	12	4	2	4	0	0	0	0	0	0	0	0
5	34	30	52	68	46	46	44	34	36	20	2	4	0	0	0	0	0
10	6	12	20	20	34	36	40	52	34	52	56	32	18	0	2	0	0
15	2	0	0		2	2	6	8	12	18	28	18	18	4	4	0	0
20	2	2	2			2	0	4	6	6	10	16	38	10	6	4	6
25						0	0		4	2	2	6	2	8	8	0	4
30						2	0		4	2	2	14	20	34	38	38	10
35							2					0	0	4	10	2	0
40												4	2	12	8	12	10
45												0	0	8	6	12	2
50												0	0	12	8	8	16
55												0	0	0	0	0	0
60												2	2	2	0	8	19
65												0		0	4	2	2
70												0		2	0	0	2
75												0		2	2	0	10
80												0		0	2	0	6
100												0		2	2	4	8
115												2					0
125												2					0
130																	2
150																	2

* INTERVALS AND SAMPLE SIZES ARE AS FOLLOWS

INTERVAL	HORIZONTAL CROSSING VELOCITY (KNOTS)	SAMPLE SIZE
1	0 THROUGH 2.0	50
2	2.0+ THROUGH 3.7	50
3	3.7+ THROUGH 5.3	50
4	5.3+ THROUGH 6.9	50
5	6.9+ THROUGH 8.1	50
6	8.1+ THROUGH 10.2	50
7	10.2+ THROUGH 12.3	50
8	12.3+ THROUGH 14.3	50
9	14.3+ THROUGH 16.8	50
10	16.8+ THROUGH 20.3	50
11	20.3+ THROUGH 25.5	50
12	25.5+ THROUGH 35.5	50
13	35.5+ THROUGH 45.8	50
14	45.8+ THROUGH 71.6	50
15	71.6+ THROUGH 77.2	50
16	77.2+ THROUGH 85.6	50
17	85.6+ THROUGH 172.3	49

In the preceding tabulation, zeros are sometimes entered explicitly and otherwise represented by blanks. By comparing these distributions to those in 5.3.11, it is noted that low crossing velocity was interpreted differently by TAHOP gunners according to whether the helicopter was approaching toward the firing tank or hovering. Zero velocity estimates are much less frequent for the target approaching with low crossing speed. It is then concluded that a hovering helicopter and a directly approaching helicopter should not be treated as equivalent targets even if both have the same size.

5.5 Constant Speed Non-Level Flight.

Basic reduced data are available for 283 firing events involving Constant Speed Non-Level flight. Data for these events have been analyzed only to the extent required for preparation of Figures 5-3 through 5-8.

5.6 Constant Speed Level Flight (Tanks Canted).

This subsection discusses the first phase analyses involving the comparison of situations where tanks are and are not canted. Only the single variable results for the implementation errors and total errors were obtained. Comparisons of basic TAHOP results for canted and non-canted tanks are made in Figures 5-24 through 5-27.

Horizontal implementation errors are compared in Figure 5-24. The mean errors show no clear trend. However, the standard deviations are consistently smaller for the canted runs. In Figure 5-25 the total horizontal errors indicate smaller mean errors for the non-canted runs. The variability (standard deviation) is smaller for the canted runs. The data in Figures 5-26 and 5-27 are too noisy to permit drawing any conclusions.

The better performance sometimes indicated by horizontal errors associated with canted tanks is not likely to be a fundamental characteristic. The canted runs were run in consecutive sequence in the second half of the test. Possibly learning effects, which have not been examined, are responsible.

5.7 Lateral Flight.

As indicated in Subsection 4.2, data for Lateral Flight situations with side-to-side pendulum type motion are included in the basic reduced data only as a subset of the Other Evasive Targets category. Data for the 75 firing events related to the Lateral Flight minimum evasive maneuver category were analyzed only to the extent needed to plot the results in Figures 5-3 through 5-8.

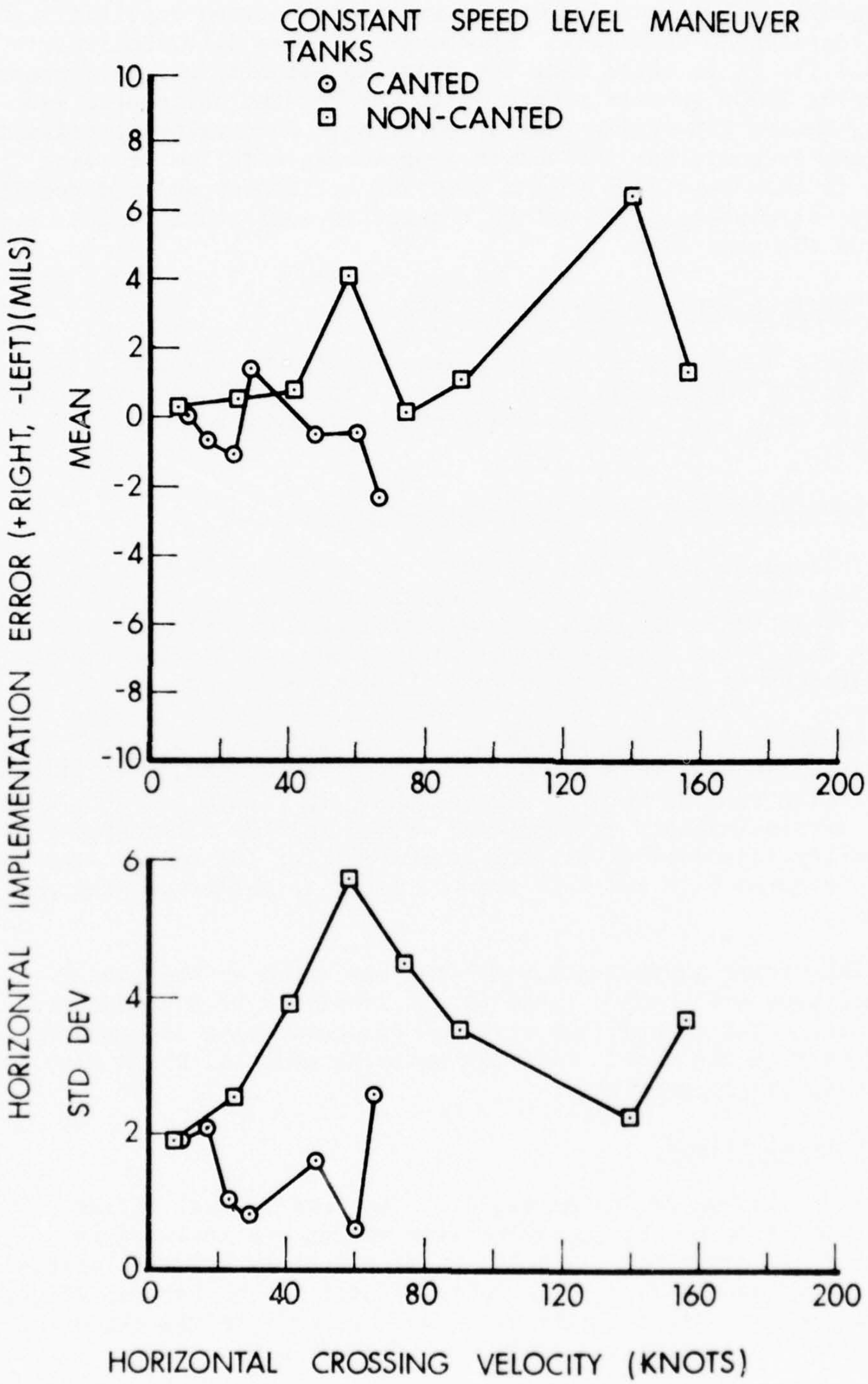

Figure 5-24. Comparison of Horizontal Implementation Errors: Canted and Non-Canted Tanks.

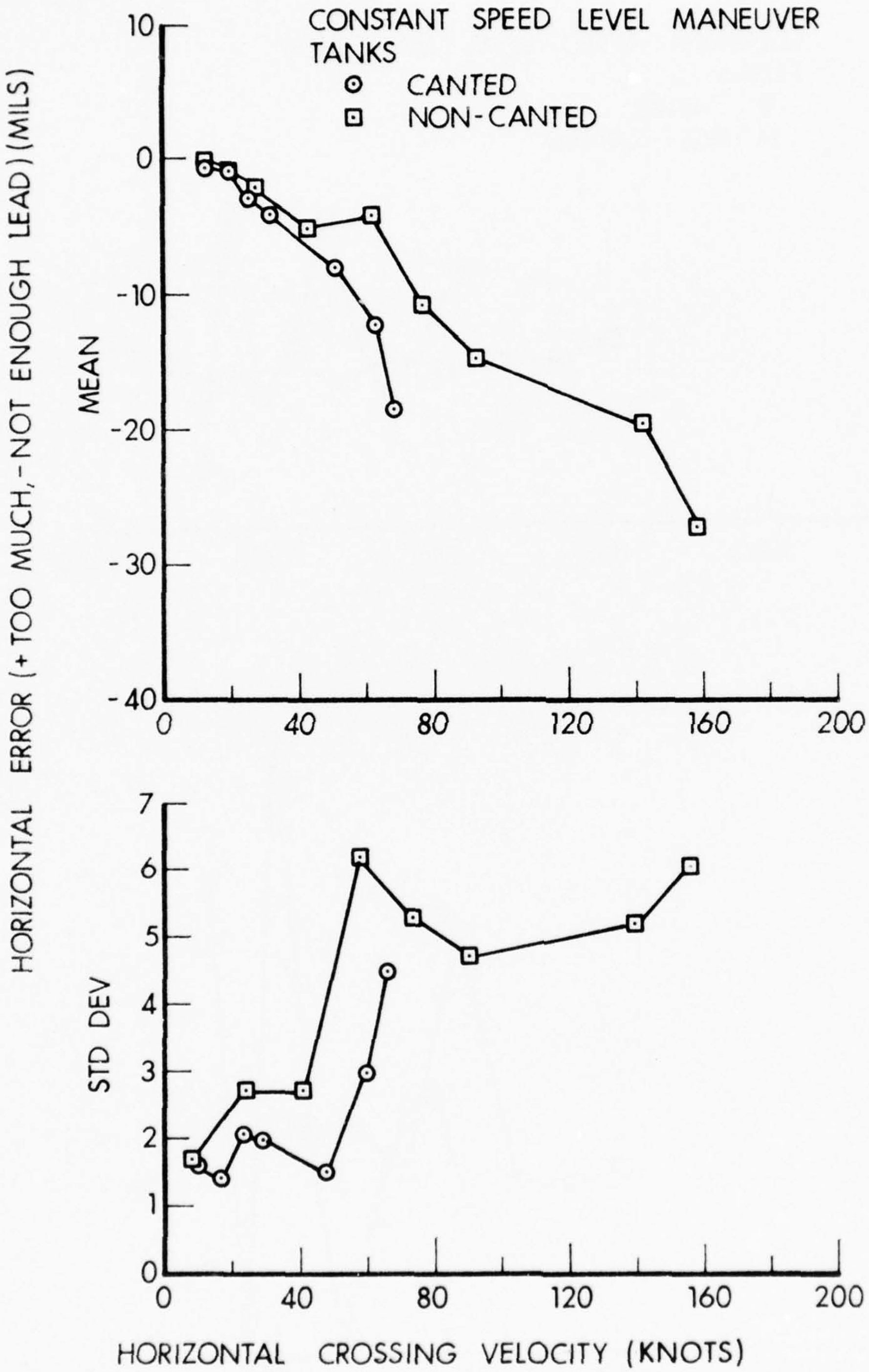

Figure 5-25. Comparison of Horizontal Errors: Canted and Non-Canted Tanks.

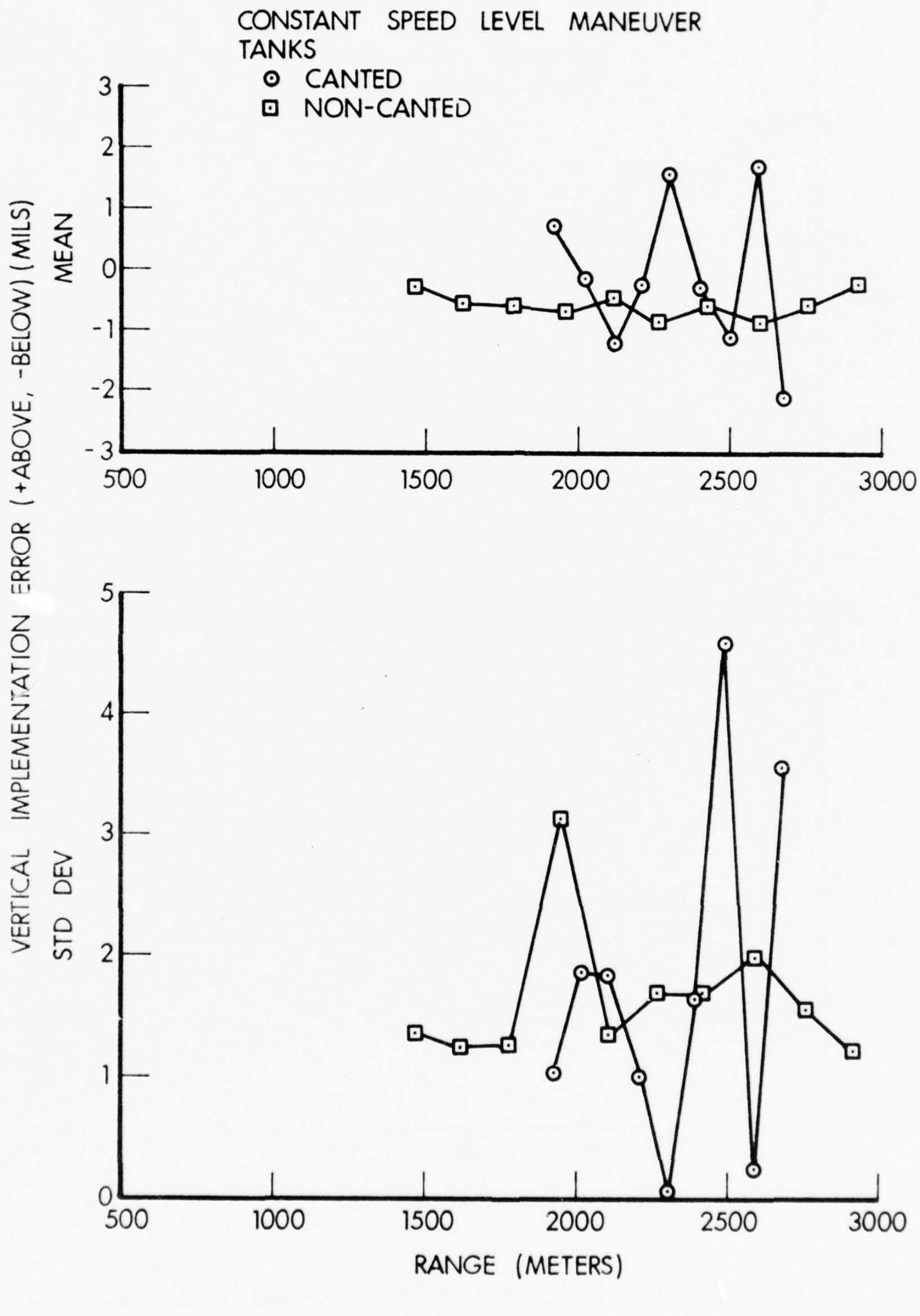

Figure 5-26. Comparison of Vertical Implementation Errors: Canted and Non-Canted Tanks.

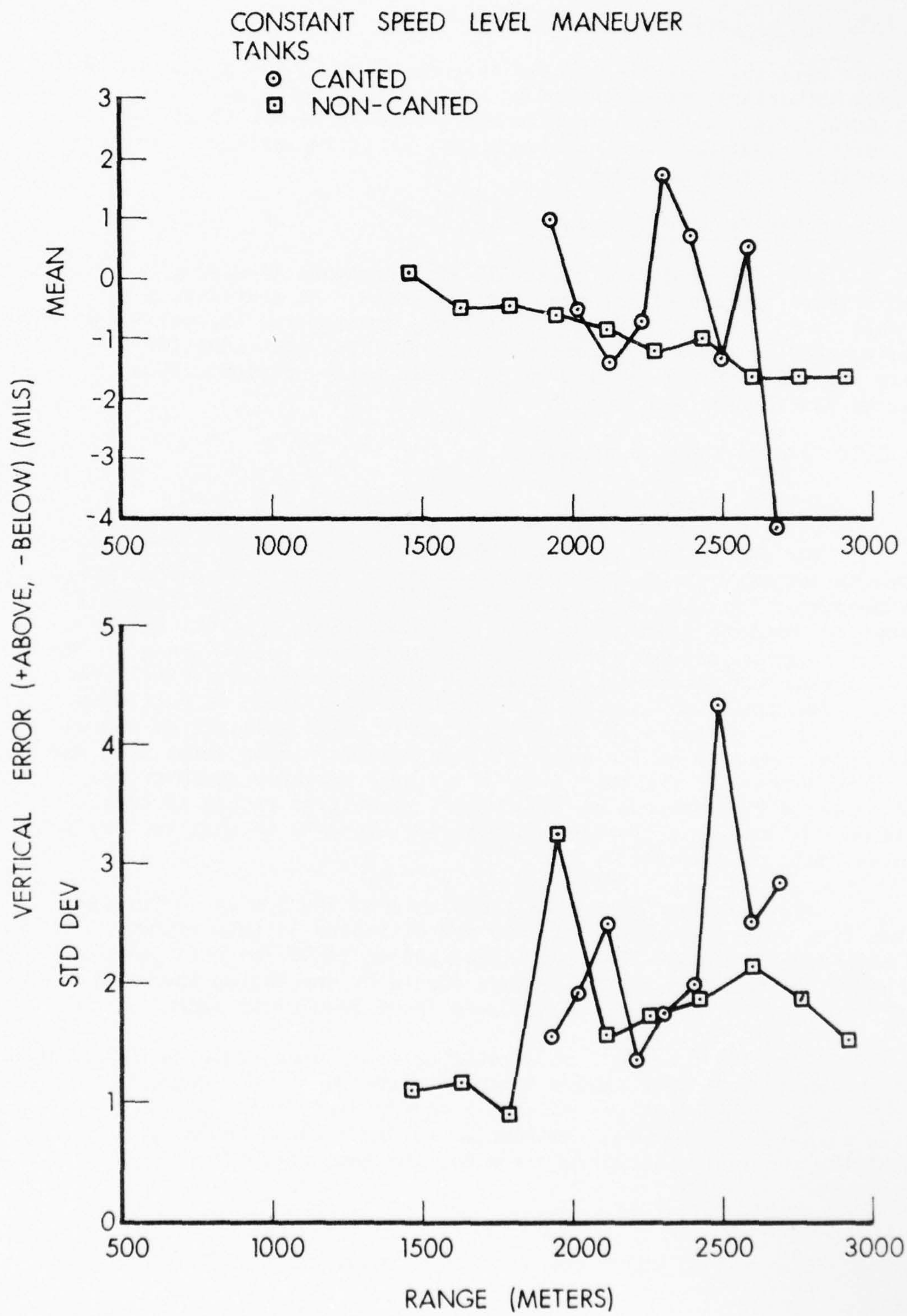

Figure 5-27. Comparison of Vertical Errors: Canted and Non-Canted Tanks.

5.8 Nap of Earth.

Data for 79 firing events corresponding to the Nap of Earth maneuver situations are contained in basic data tabulations. The helicopter target flew too close to the ground to permit obtaining satisfactory radar data and, consequently, it is impossible to include any results for this maneuver.

5.9 Other Evasive Targets.

Basic reduced data cover 315 firing events involving Other Evasive Targets flying over various paths. As stated in 5.7 (as well as in Subsection 4.2), 75 of these are for the Lateral Flight (Side-to-side pendulum type motion) category. The remaining 240 events related to Other Evasive Targets have been analyzed only as required for Figures 5-3 through 5-8.

5.10 Add-On TAHOP Results.

5.10.1 Introduction.

The add-on test was restricted to a single M60A1 simulating tankswith automatic lead fire control systems. On each occasion, the tank conducted two simulated firings. The first firing represented an attempt to simulate a dual-axis lead computing sight system. Neither lead nor range adjustments were supposed to be made by the gunner. The second firing was intended to simulate a single-axis (horizontal) lead system. The gunner was supposed to apply vertical lead, as necessary. This subsection presents the results of first phase analyses of add-on TAHOP data. Because of the comparatively smaller sample sizes than for the basic portion of the test, only the single variable approach was used. Random fluctuations in the results were large enough to cast doubt on the utility of further subdividing the data so that two variable results could be discerned.

It should be noted that components of the system error due to the fire control lead errors were not estimated in this study, although some data were measured in the add-on TAHOP for this purpose. The effect of the fire control errors should be remembered when any comparison between the basic and add-on TAHOP results is made.

This first attempt at organizing the add-on TAHOP data indicates that the gunners did not always follow instructions. The comments in the following subsections reflect a superficial review of the available data. A thorough examination to understand the reasons underlying the indicated performance has not been attempted.

5.10.2 First Firings.

Figure 5-28 shows the horizontal total error referenced to the

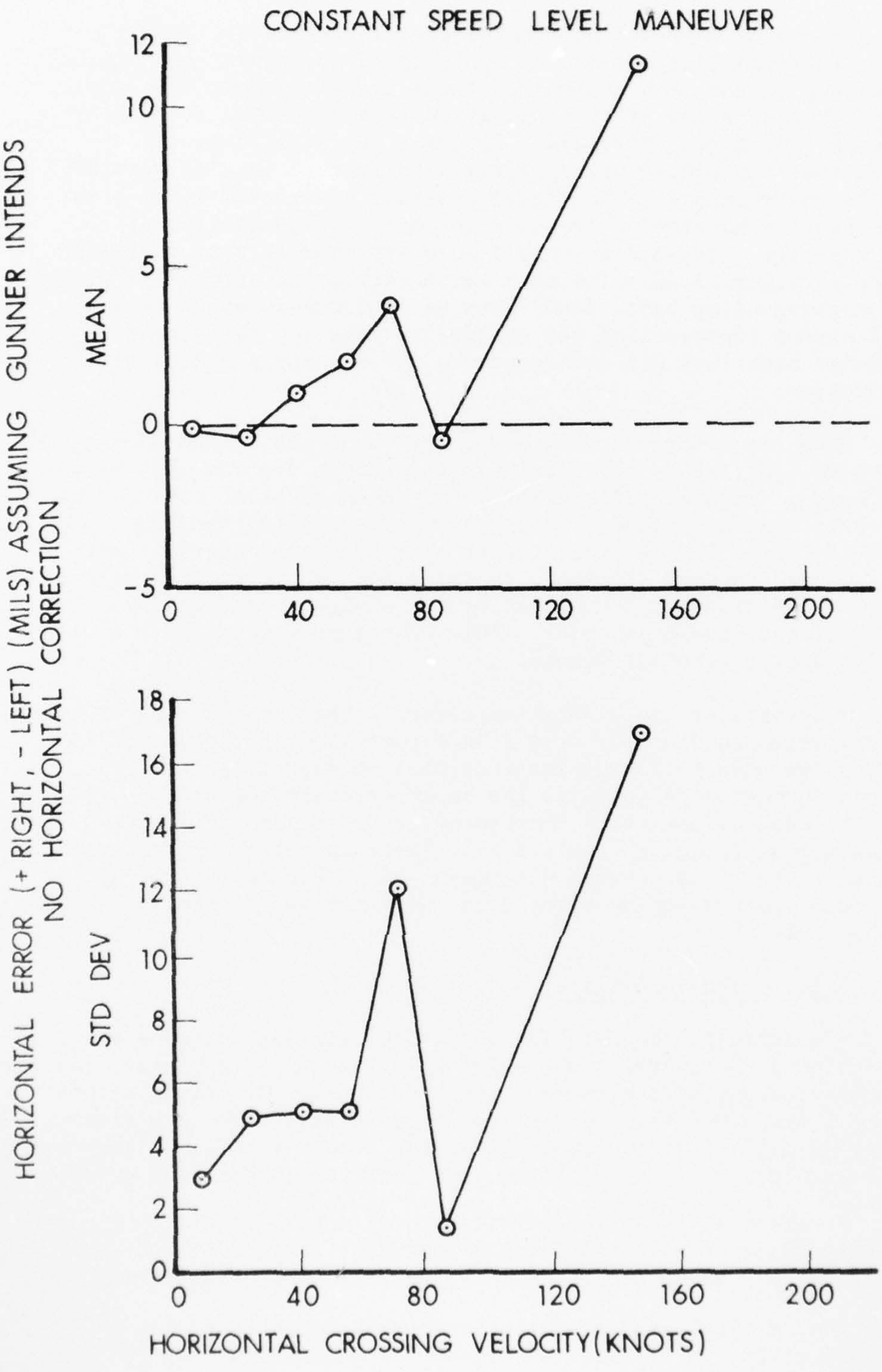

Figure 5-28. First Firing Horizontal Error Assuming Gunner Followed Instructions.

horizontal coordinate versus horizontal crossing velocity, assuming the gunner followed instructions by applying no horizontal correction. The large jump in the mean horizontal total error at about 150 knots can be better understood if it is surmised that sometimes the gunner was applying some horizontal lead. Figure 5-29 is based on the assumption that the gunner was applying a horizontal lead correction, contrary to instructions. The figure presents horizontal total error referenced to the horizontal crossing velocity versus horizontal crossing velocity. Results in this figure are clearly very different from those in Figure 5-28. The mean horizontal total errors are worse than the corresponding basic TAHOP data in Figure 5-3, which is what one would expect (considering the assumption made for the second figure) if the gunner sometimes did and sometimes did not apply a horizontal lead correction.

When the vertical total errors are analyzed, there once again appears to be a difference between what the gunner did and what he was supposed to do. Figure 5-30 shows that the mean vertical total error is positively biased if gunners are assumed to have followed the instructions (Curve I), but that the error more nearly averages zero if it is assumed gunners attempted to apply the superelevation correction (Curve II). The standard deviations do not change significantly regardless of the assumption made. This indicates a shift of the mean errors by a nearly constant amount.

The vertical implementation error is the same as the vertical total error corresponding to Curve I in Figure 5-30 if the gunner is assumed to have been following instructions. However, it is more likely that gunners were applying the superelevation correction. Vertical implementation errors corresponding to this more likely assumption are depicted in Figure 5-31. The mean errors in this figure are similar to those associated with Curve II of Figure 5-30 except that the mean implementation error does not increase as much for ranges beyond 2500 meters.

5.10.3 Second Firings.

Simulated firing data for the second firings indicate that the gunners followed the instructions related to the single-axis (horizontal) lead computing sight more closely. In Figure 5-32, the mean horizontal total errors are close to zero and the standard deviations are also relatively small. If it is assumed that the gunner intends no corrections, the error in Figure 5-32 is also the horizontal implementation error.

Figure 5-33 shows the vertical total error assuming the gunner applies only the vertical lead. Except for fluctuations at 1600 and 1800 meters, the mean vertical total errors seem to average about zero.

The vertical implementation errors depicted in Figure 5-34 seem similar to the vertical total errors in the previous figure.

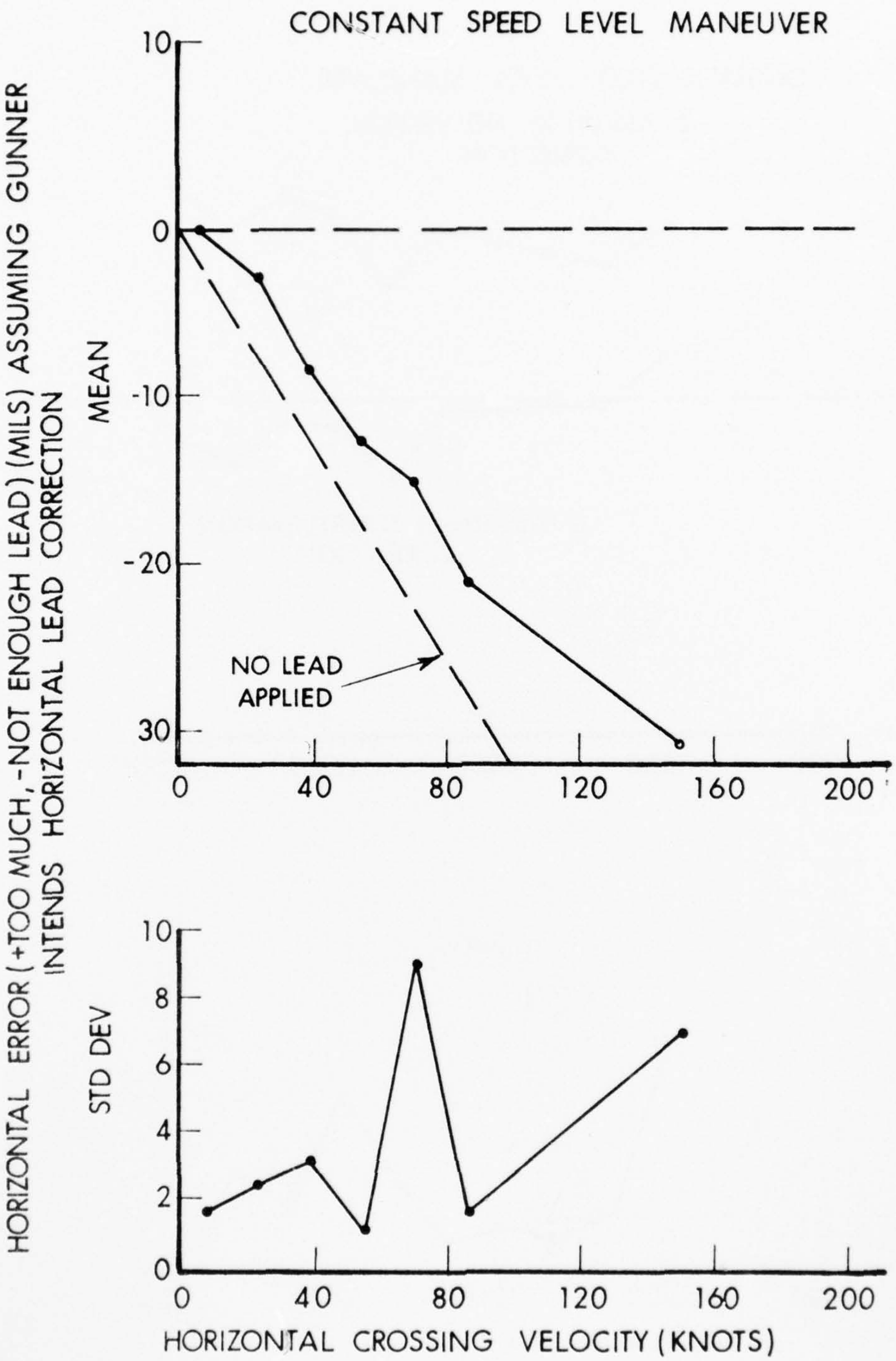

Figure 5-29. First Firing Horizontal Error Assuming Gunner Intends Lead Correction.

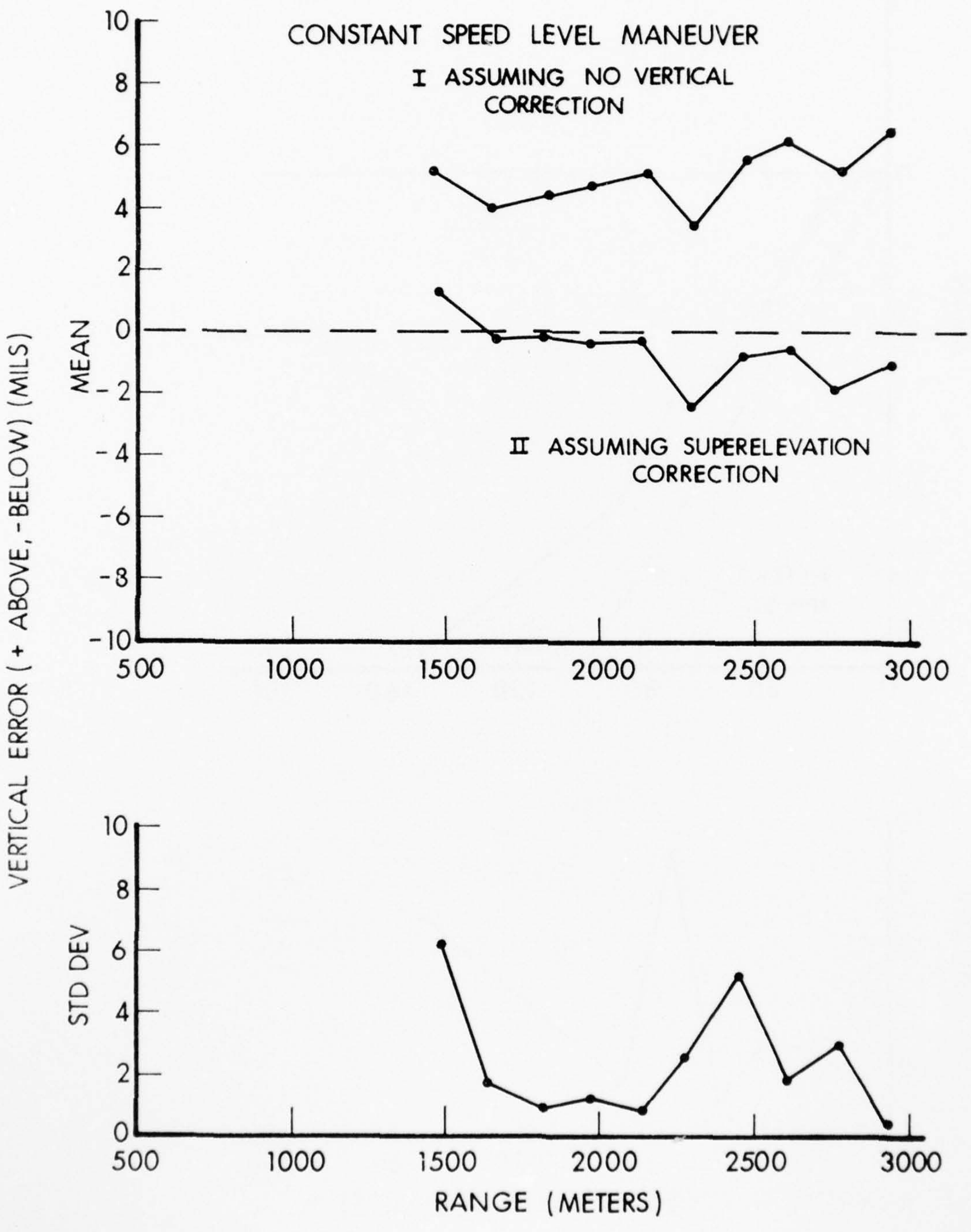

Figure 5-30. First Firing Vertical Error.

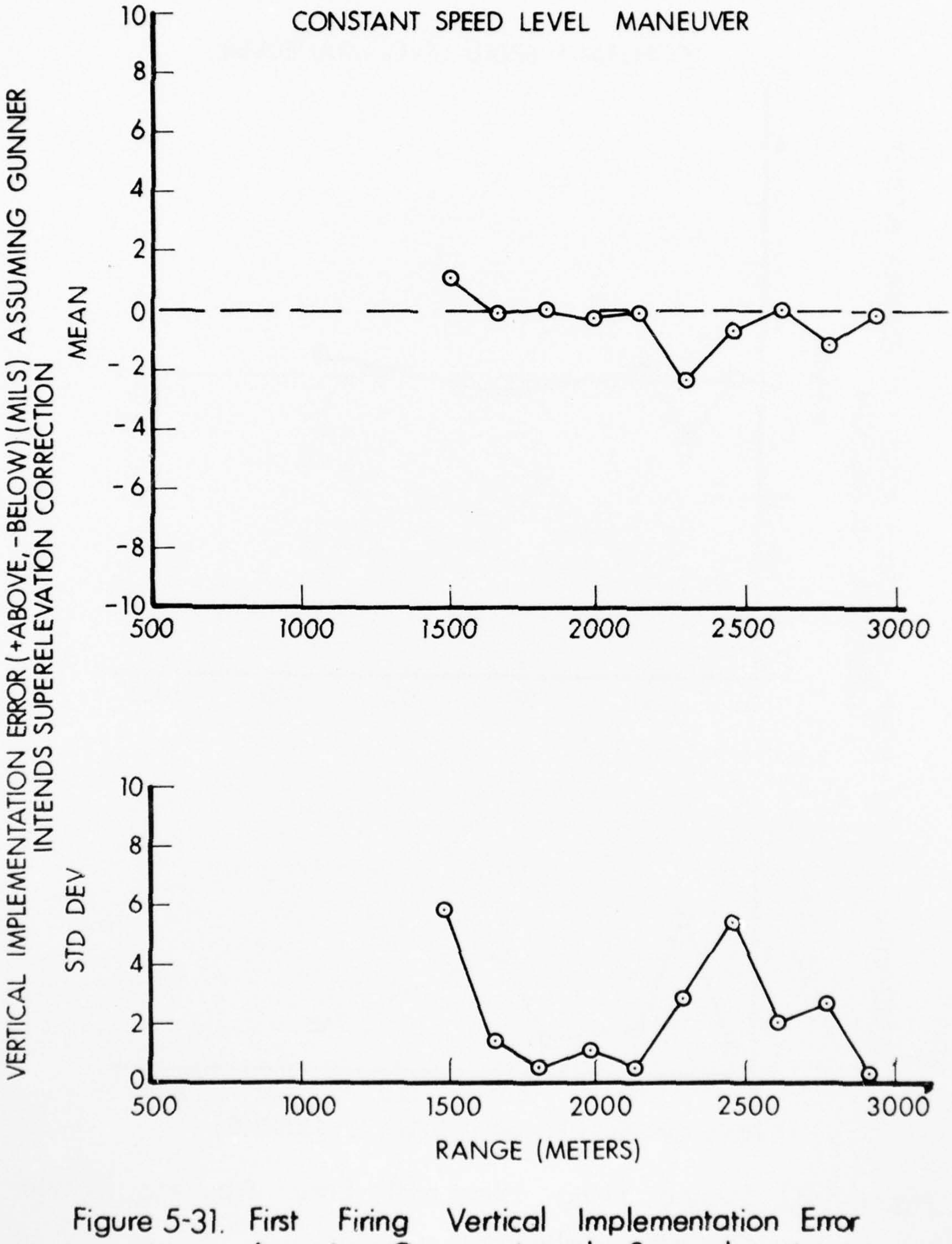

Figure 5-31. First Firing Vertical Implementation Error Assuming Gunner Intends Superelevation Correction.

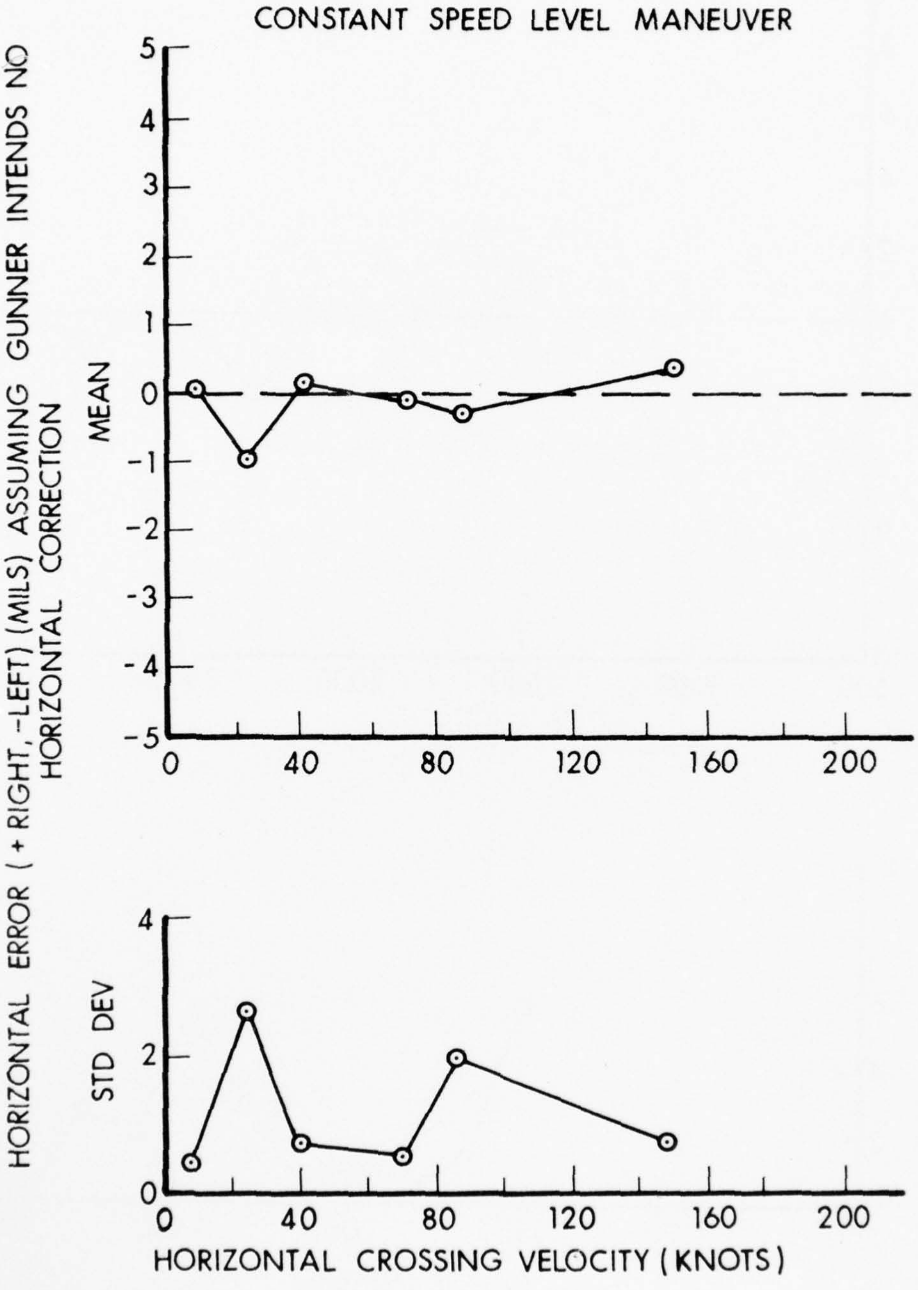

Figure 5-32. Second Firing Horizontal Error Assuming Gunner Followed Instructions.

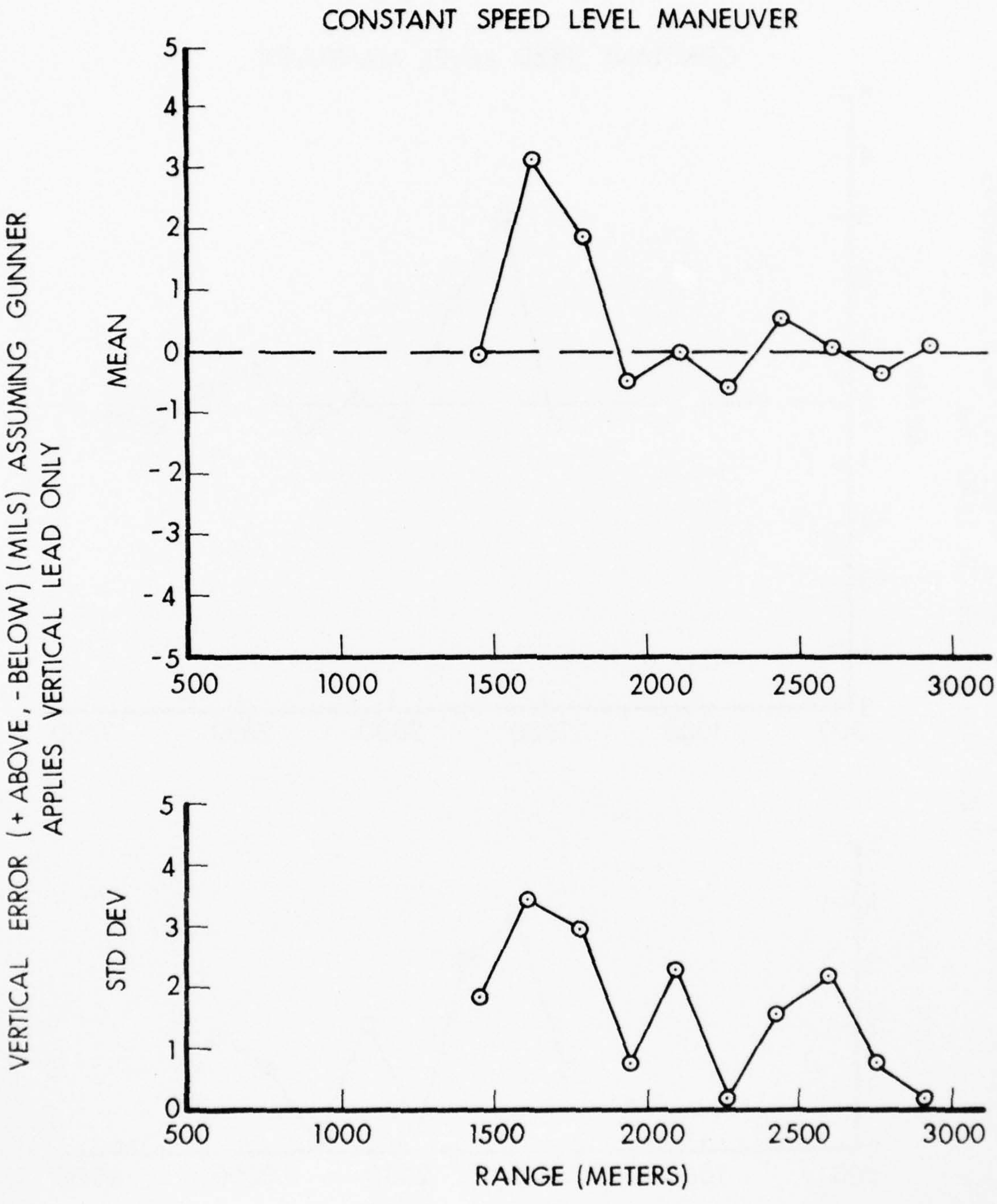

Figure 5-33. Second Firing Vertical Error Assuming Gunner Followed Instructions.

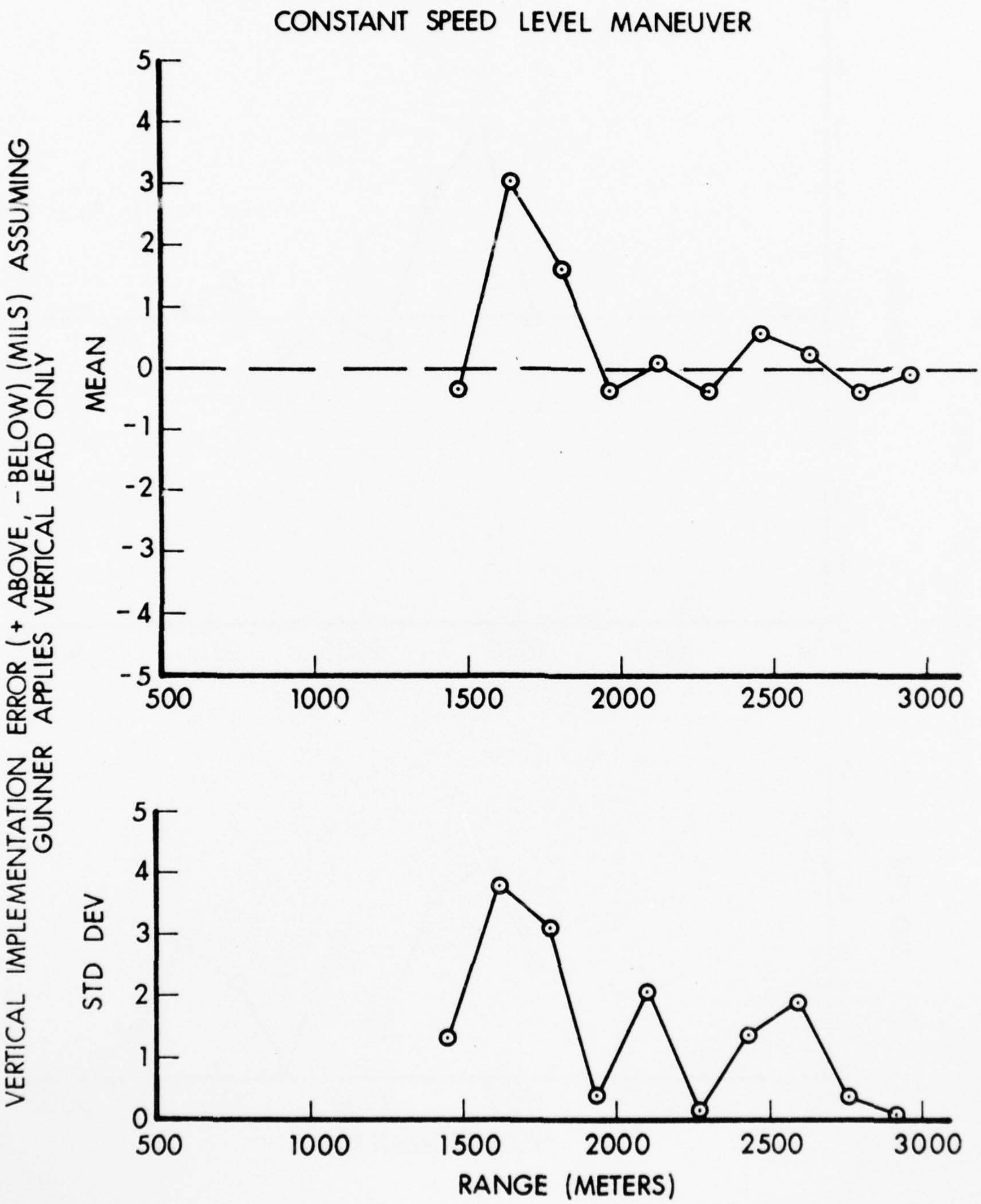

Figure 5-34. Second Firing Vertical Implementation Error Assuming Gunner Followed Instructions.

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APPENDIX A - AMSAA LETTER TO CDEC CONCERNING TAHOP TEST PLAN

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DEPARTMENT OF THE ARMY Mr. Conroy/myl/870-3675
U.S. ARMY MATERIEL SYSTEMS ANALYSIS AGENCY
Aberdeen Proving Ground, Maryland 21005

18 JAN 1973

AMXSY-GA

SUBJECT: **Tank vs Helicopter Kill Probabilities for Experiment 43.8**

Commander
US Army Combat Developments
Experimentation Command
ATTN: CDCEC-PL-M (MAJ Catron)
Fort Ord, California 93941

1. Attached you will find a discussion of AMSAA requirements for delivery accuracy test data to support kill probability estimates for the T62 tank with 115 APDS ammunition and telescopic sight vs COBRA helicopters in Experiment 43.8. AMSAA feels the testing should be expanded to include more sophisticated fire controls. The T62 tank with 115 APDS ammunition and telescopic sight will have a limited capability against helicopters with moderate or high crossing velocities. The addition of a laser range finder and lead computer, a technically feasible addition, could provide a substantial increase in the performance. AMSAA also feels that information on the capabilities of US tanks against helicopters should be obtained since it is almost inconceivable that the US will not eventually face the same type of helicopter threat. It would seem wise both from an economic and a compatibility of data viewpoint to acquire all of this data together.

2. The additional aspects of this testing will be explored on 19 Jan 1973 when CDCEC personnel visit AMSAA.

FOR THE DIRECTOR:

1 Incl
as

MORGAN G. SMITH
Chief, Ground Warfare Division

1 - JAN 1973

PLAN OF TEST OF THE CAPABILITY OF WELL-TRAINED GUNNERS TO HIT HELICOPTER TARGETS WITH A HIGH VELOCITY APDS ROUND FIRED FROM A TANK WITH A SIMPLE SIGHT FIRE CONTROL SYSTEM

The U.S. Army Combat Developments Experimentation Command (CDEC) has requested AMSAA support of a test of the attack helicopter in a daylight attack (Experiment 43.8). One of the types of data requested was kill probabilities for Soviet T-62's firing the main gun at the helicopter. Because of a lack of adequate background data to support such estimates, CDEC will conduct a supplemental test (TAHOP) to establish the capabilities of such a system to engage helicopters.

Soviet crews and equipment are obviously not available for the experiment. U.S. crews and equipment can be made available. However, U.S. tank gunners have very infrequent firing experience with APDS ammunition and usually do not gain experience over a long term because they tend not to stay long as a gunner even if they make a career of the Army. The latter is apparently not true in the Soviet army and may permit a substantial number of Soviet gunners to have some experience firing APDS ammunition against moving targets. In any event, it seems that the desirability of an attack helicopter should be based on an opposing force with at least moderate training to counter the helicopter rather than the training, or lack thereof, which is relevant to a situation where the attack helicopter is not a part of the enemy threat. Therefore, it seems desirable to conduct a training phase as the first part of TAHOP.

Before discussing the training phase of the TAHOP, it seems desirable to be more specific about the objective of TAHOP and to explain why certain elements are not included.

The objective of Experiment 43.8 is to evaluate the performance of attack helicopters as part of an armored force attacking an enemy armored force. The friendly helicopter is to be the Cobra (AH-1G). The tank in the enemy force is to be the Soviet medium tank, T-62. The performance of the T-62 against the helicopter in Experiment 43.8 is made up of capabilities in the following areas.

Incl 1

- Acquisition
- Reliability
- Rate of fire
- Delivery accuracy
- Terminal effects

The target acquisition and rate of fire capabilities will be determined directly during Experiment 43.8*. The reliability of the gun/ammunition/ fire control/turret controls, given a working system at the start of the action, is good enough that the probability of any failure during such an encounter is negligible. (Failure prior to the encounter would be reflected by availability of the system. This is not being directly evaluated in Experiment 43.8). The terminal effects are to be assessed as the probability of causing the helicopter to abort its current attack. The estimate of this capability for the 115 APDS round is 1.0, given a hit.

With the acquisition and rate of fire being determined in Experiment 43.8 and no degradation associated with terminal effects or the reliability aspects pertinent for the test, i.e., probability of kill, given a hit and reliability estimates as 1.0, the only remaining element is delivery accuracy, which will therefore be the element of interest in TAHOP.

The elements influencing delivery accuracy can be separated into three groups to further isolate the elements of interest in TAHOP. These groups are:

- Alignment (zeroing)
- Tank and environment related items (cant and air density for example), and
- Range and lead

The influence of the first two groups has been determined for ground targets and will not change appreciably for this system when firing against helicopters in the engagements possible in Experiment 43.8. Since inclusion of these elements in TAHOP would substantially increase the scope of the test with an excellent chance of adding information only by confirmation of the current understanding, TAHOP will be designed to exclude these effects. Only in the event that an element in one of the first two groups has a side effect of influencing the range and lead error will it be specifically varied and recorded in TAHOP.

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* Care must be taken to have the gunner perform in the simulated firings as closely as possible to how he would in live fire situations.

AD-A038 065 ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY ABERDEEN PROV--ETC F/G 19/5
ANALYSIS OF GUNNER AIM ERRORS FROM THE TANK AGAINST HELICOPTER --ETC(U)
JAN 77 J A CHERNICK, R C CONROY, B N GOULET

UNCLASSIFIED AMSAA-TR-192 NL

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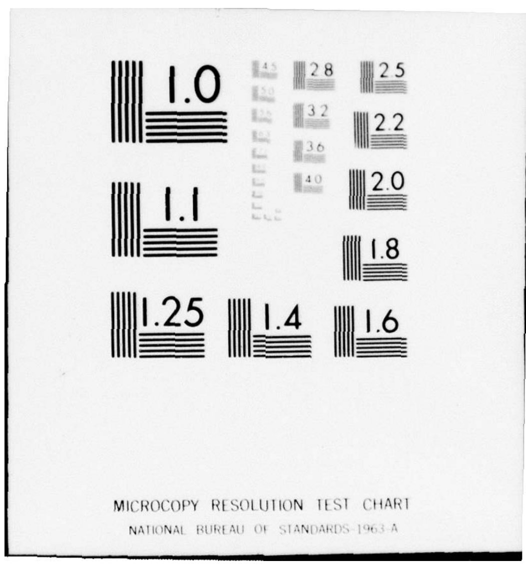
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

This leaves range and lead as the elements of interest in TAHOP.

The primary fire control of the T-62 tank is the gunner's telescope with a built-in ballistic reticle. Such a system has a vertical line which indicates the expected horizontal position of the round and horizontal marks which are used to indicate the vertical position of the round at the indicated range. Additional vertical lines and their spacing are provided as reference for implementation of lead estimates. Finally a small stadia range finder is located near the edge of the field of view.

The task for the gunner is to determine where the target will be at the time the round would reach the target and superimpose a point on the vertical line corresponding to the target's range on that position. To do this involves competence in four areas.

- Range estimation
- Speed estimation
- Mental calculation of lead based on velocity estimates and, to a lesser extent, range estimates
- Implementation of the mental calculations of lead

The training phase in TAHOP should insure that the gunners have reached a plateau in their capability in each of the four areas.

RANGE ESTIMATION

The ranges of interest in this test are expected to be between 1500 and 3000 meters. Primary emphasis should be placed on these ranges.

Soviet doctrine calls for the commander to determine the range to vehicular targets with the aid of his stadia range finder. If this procedure were followed, two crew members would be required for each vehicle in the test and a good approximation of the stadia and optics of the T-62 would be required in the test vehicles. The difference between stadia range finder performance and visual range estimation is not large for ground targets. The accuracy of the stadia range finder should decrease, approaching the error magnitude associated with visual range estimation, as a result of the larger variation in vertical dimension of the target presented to the tank, because of the pitch

and roll motions of the helicopter. Finally, the APDS round is much less sensitive than most rounds to errors in range (3.5m total difference between 1500 meters and 3000 meters) making small differences in ranging errors of minor consequence.

It is therefore recommended that the gunner provide his own range estimates, based on visual range estimation through his telescope, rather than use of a stadia range finder, for this test.

One possible complication associated with visual range estimation is that the background adjacent to the target will probably influence the accuracy of the range estimates. For example, visual range estimation for a helicopter silhouetted against a clear sky background with no ground objects or clouds in the field of view will be solely dependent on the gunner's ability to relate target size to range. However, the helicopter tactics to be used in Experiment 43.8 call for altitudes which will ensure that the horizon will always be in the field of view and normally some nearby (to the target) ground objects will also be generally visible. Though a helicopter at moderately high altitudes would be harder for the tank to hit, it is anticipated that such a tactic would not be used. The high altitudes would increase the helicopter's exposure time, make it more readily acquired by more elements on the battlefield, and, thereby, increase its likelihood of being destroyed.

SPEED ESTIMATION

The maximum speed of the COBRA is approximately 150 knots. However, limited data available indicate that much lower velocities will induce substantial lead errors. In addition, the extremely high helicopter velocities are not compatible with the doctrine to be employed in Experiment 43.8. It is expected that the lead errors associated with speeds of 75 knots will produce very low hitting probabilities (generally less than .1 at 1500 meters and beyond). It is therefore recommended that the training phase emphasize speeds from hover to 75 knots with very limited operation at higher speeds.

For scenes which contain a target near the horizon and/or other ground objects, it is anticipated that the gunner can estimate target speeds as

well as a commander could. Again, to reduce personnel requirements, it is recommended that the gunner estimate the target speed.

The target speed of interest is the component in the plane perpendicular to the line of sight. The lead which should be applied will vary in magnitude with the speed and should be applied in the apparent direction that the target is moving. The component tending to change the range can be ignored because even at 150 knots, it will be small compared to the visual range estimation errors. For example, the largest range change (during the projectile's time of flight) of interest will be approximately 150 meters - a 150 knot helicopter approaching the tank at a nominal range of 3000 meters.

The influence of background could even be greater on speed estimates than on range estimates, but the conditions selected for this test should minimize the effect.

MENTAL CALCULATION OF LEAD

The selection of the APDS round permits simplification of the mental calculation of lead. The lead requirement changes by only 10% from the muzzle to 3000 meters range for this round. A factor of 1/3 $\not{m}$ per knot corresponds to approximately 1000 meters range but will be adequate for all ranges involved in this test.

IMPLEMENTATION OF THE MENTAL LEAD CALCULATION

Implementation of the mental lead calculation is simply the transformation of the number in the gunner's mind into a displacement on the sight reticle. Though both the calculation and the implementation are probably more indoctrination than training, the capabilities of the gunners to perform these operations should be confirmed.

(The gunners selected for TAHOP should not have been exposed to any of the TAHOP test sites prior to or during the training phase of the test.)

THE TAHOP EXPERIMENT

The purpose of the TAHOP Experiment is to collect data which will provide the basis for devloping estimates of the capability of tank gunners to point their sights at a proper point to compensate for target motion and range.

INSTRUMENTATION

The primary data in this test will come from analysis of movie films taken with cameras mounted on the gun tube near the turret or on the mantlet of each tank.* Color film has been shown to produce acceptable images under similar conditions in prior tests. If the cost difference between black and white and color film warrants, a preliminary investigation of the adequacy of black and white film could be conducted. The primary property of concern is the ability to define the location of the center of mass of the helicopter. The pervious experience indicates that measurement errors not greater than 0.1 ₥ r.m.s. should be achievable with color film. If this is also representative of the errors associated with black and white film, either would be acceptable.

The camera must have reticles which will appear on the exposed film. The cameras must also be able to be aligned parallel to the telescope's line of sight. It is desirable that a time reference be available either from a timing light exposing lines at the edge of the film or from some other suitable method. Framing rates of 20 to 50 frames per second are acceptable.

The film will be the only source of data for telescope pointing direction with respect to the target at the time of firing. This is the primary data required from this test. Additional data which could be obtained from the film includes target motion perpendicular to the line of sight. However, data reduction from the film is a time consuming process. The motion along

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* The data desired from these films could also be collected using beam splitters and cameras mounted on the M60's telescope or adapting shillelagh trackers and missile sources. However, such equipment is not known to be available.

the line of sight is also of interest, but cannot be determined from the film. Therefore, an alternate method of determining target motion during the exposure of the helicopter is very desirable. The target motion measurements should be synchronized with the timing marks on the film.

Items which fall in a nice to have, but not essential, category are the azimuth, elevation, and speed of the helicopter relative to the direction to each of the tanks.

Finally, data sheets which relate run numbers, nominal conditions, film identification, calibration runs, and comments are required.

TEST PROCEDURES

Five M60A1 tanks with gunners viewing through the M105D telescopes and using the turret controls (power mode) should be located in close proximity to each other. Adjacent tanks should not interfere with turret movement or obstruct vision to the area where the target will be. The tanks should be kept close enough together that the differences in target ranges, exposure times, and presented areas will be trivial.

Each run should start with the gunner tracking the target near the edge of the field of view. Following a command, identifiable via the time synchronization system, the gunner should estimate the target range, estimate the target speed, decide what lead to use, apply the lead, and simulate firing by pulling the trigger. The trigger pull must be identifiable via the time synchronization system. A record of the gunner's range estimate, and lead estimate would be desirable, but is not essential.

Following the simulated firing of the first round, the gunner should move the turret so that the target is again at the edge of the field of view. The gunner should then repeat the previous procedure, without command, to produce a second simulated firing.

In scheduling the runs, the range and helicopter velocity should change between runs on nearly every occasion. The position of the tanks should be changed frequently to prevent the crews from repeating runs under nearly identical conditions.

The following runs make up the basic portion of the test.

Run	Target Direction	Nominal Range ($\pm$ 10%)	Cant	Helicopter Climb Rate (%)
A	0	1500	0^{o}	0
B	90	1500	0^{o}	0
C	90	2000	0^{o}	0
D	90	2500	0^{o}	0
E	0	2500	0^{o}	0
F	15	2500	0^{o}	0
G	90	2000	3^{o}	0
H	90	2000	10^{o}	0
I	90	2500	0^{o}	Var. (NOE)*
J	90	1500	0^{o}	Var. (NOE)*
K	90	1500	0^{o}	10% Down
L	90	2500	0^{o}	10% Down
M	90	1500	0^{o}	10% Up
N	90	2500	0^{o}	10% Up
O	90	1500	0^{o}	20% Down
P	90	2500	0^{o}	20% Down
Q	90	1500	0^{o}	20% Up
R	90	2500	0^{o}	20% Up
S	45	2500	0^{o}	0
T	45	2500	10^{o}	0

*NOE - Nap of earth

Speed (Knots)	Run Type	No. of Reps. Per Gunner
HOVER	B	26
	C	26
	D	26
10	A	6
	B	6
	C	26
	D	6
	E	6
	F	6
	G	6
	H	6
	I	12
	J	12
	K	4
	L	4
	M	4
	N	4
	O	4
	P	4
	Q	4
	R	4
20	A	6
	B	6
	C	26
	D	6
	E	6
	F	6
	G	6
	H	6
	I	12
	J	12
	K	4
	L	4
	M	4
	N	4
	O	4
	P	4
	Q	4
	R	4
35	B	6
	D	6
75	B	6
	C	26
	D	6
	S	6
	T	6
150	B	6
	D	6
		Total 400
		÷ 2 = 200 Runs
		χ 5 = 2000 Data Points

The preceding runs, except for the nap of earth flights, do not generally include accelerations of helicopters while the gunners are engaging them as targets. Current expectations are that the helicopter cannot accelerate rapidly at airspeeds less than 30 knots and that at speeds much above 30 knots (and ranges greater than 1500 meters) the lead estimation capability of the gunner will be poor enough to produce low hit probabilities from that cause alone. Therefore, at this time, it seems appropriate to plan a series of runs with the target helicopters accelerating.* The nominal speeds for these runs should be 20 and 30 knots and should cover the three ranges used in the previous portion of the test. Approximately 50 runs should give a good idea as to whether accelerations can contribute significantly to the capability of the gunner to make the proper lay.

Data reduction and analysis during the test is desired to check whether high speeds induce the poor performance expected and whether accelerations which can be achieved substantially influence the capability of gunner to make an appropriate lay. Such information could lead to selection of specific test conditions which would improve the relevance of the runs conducted during the latter portion of the test.

CALIBRATION

Each time a camera is loaded with film**, the first few frames should be exposed on an alignment target that has an aimpoint for the gunner's telescope and a second aimpoint for the camera. These two aimpoints should be offset by the same dimensions separating the gun and camera on the tank thereby making the camera axis parallel to the sight axis.

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* For the runs with accelerating helicopter targets, instruct the pilots to accelerate (turns, climbs, dives, speed up and slow downs) as much as they can while staying generally at the speed level indicated.

** If the tanks are moved after loading the cameras, this procedure should be repeated at the new location.

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APPENDIX B - AMSAA LETTER TO CDEC CONCERNING ADD-ON PORTION OF TAHOP

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US Army Materiel Systems Analysis Agency
Aberdeen Proving Ground

Mr. Conroy/myl/870-3675

30 APR 1973

AMXSY-GA

SUBJECT: Expansion of TAHOP Experiment

Commander
US Army Combat Developments
Experimentation Command
ATTN: CDEC-PL-N (MAJ Catron)
Fort Ord, California 93941

1. Reference is made to: Letter, AMXSY-GA to CDCEC-PL-N, 18 Jan 73, Subject: Tank vs Helicopter Kill Probabilities for Experiment 43.8.

2. In the reference letter AMSAA outlined test requirements in support of estimates of the capability of a Soviet T62 to kill a US attack helicopter. Also in that letter AMSAA indicated that it is desirable to collect supplemental data during that test to support estimates for slightly modified Soviet tanks and US developmental tanks. Inclosures 1 and 2 to this letter develop the philosophy associated with the requested expansion and an outline of the test requirements.

FOR THE DIRECTOR:

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as

MORGAN G. SMITH
Chief, Ground Warfare Division

APR 1973

EXPANSION OF THE TAHOP EXPERIMENT - GENERAL

The US Army Combat Developments Experimentation Command (CDEC) has requested AMSAA support for a test of the attack helicopter in a daylight attack (Experiment 43.8). One of the types of data requested by CDEC was kill probabilities for Soviet T62's firing the main gun at the attack helicopter. Because of a lack of adequate background data to support such estimates, CDEC will conduct a supplemental test (TAHOP) to enable AMSAA to provide valid estimates of the capabilities of such a system to engage helicopters.

In a letter to CDEC, dated 18 January 1973, AMSAA outlined a test which would obtain data required for estimating the performance of the Soviet T62 firing APDS against attack helicopters. It is expected by AMSAA that the test as specified will produce the data required to support the estimates desired by CDEC for Experiment 43.8. However, as AMSAA indicated in the 18 January 1973 letter, if data relevant to either new US tanks firing at hypothetical Soviet attack helicopters or to modified Soviet tanks firing at US attack helicopters are to be obtained TAHOP must be expanded. The addition of a laser rangefinder and a lead computer, a technically feasible addition, would be expected to make a major change in the capabilities of the Soviet tanks against this type of target. This letter is being written to outline a way that TAHOP might be expanded to obtain basic data to support estimates for such systems.

The letter of 18 January 1973 contains a breakdown of the elements contributing to tank (main gun, conventional ammunition) vs helicopter

Incl 1

kill probabilities. These elements are acquisition, reliability, rate of fire, delivery accuracy, and terminal effects. In a subsequent discussion in that letter four of the elements are identified as not of direct concern in TAHOP because they can adequately be determined from other sources. The remaining element, delivery accuracy, is stripped of all error contributors except range estimation and lead. The other error contributors are reasonably well understood and, if included in TAHOP, would expand the difficulties in sampling from appropriate conditions, drastically increase the instrumentation requirements, and require a precision in instrumentation and accuracy in data reduction beyond that which is compatible with TAHOP. Substantial data on range estimation capabilities already exists. However, there are two reasons for including it in TAHOP.

- Range estimation errors may be somewhat greater for targets in the air than for ground targets because of the greater distances from the target to adjacent prominent terrain features, and
- range estimation, like lead, is applied, when using a ballistic reticle, by the gunner determining a point on the reticle to be placed on the target. As such, the gunner's aim at the time of firing is made up of his intentional combination of lead and lay as well as limitations derived from his inability to execute his intentions with perfection. Since these items may be interrelated it is advisable to include them all in the test.

Lead obviously must be included in the test because it is the major factor influencing the degradation in the tank's capabilities for moving helicopter targets.

The magnitudesof the range estimation and lead errors are primarily influenced by motion of the target, lead related items of the fire control hardware, characteristics of the ammunition, and capabilities of gunners to perform their tasks. Target motion conditions will be varied in TAHOP to determine the influence of target motion on range estimation and lead errors. The lead related items of the fire control hardware and ammunition characteristics generally determine the tasks the gunner attempts to perform. The major exception to this is the application of the burst on target doctrine which fundamentally ignores the fire control and characteristics peculiar to the ammunition being fired.

The four fundamentally different tasks that gunners may be required to perform when firing a tank gun at a helicopter target (for current tank fire control concepts) are as follows:

a. Simple Sight Ballistic Reticle

The gunner is required to apply a sight picture which produces lead for a target in the direction of its apparent motion. Though this will frequently require lead in both the azimuth and elevation directions in the gunner's sight, the gunner's mental processes can be restricted to estimating the total apparent target velocity, mentally converting that into the required lead angle, and applying the lead in the direction of target motion.

b. Lead Computer/Lead Compensation - Azimuth Axis

The gunner is required to track the target in one direction, azimuth, and create a sight picture which applies lead in the other

direction, elevation. In this case the gunner must estimate the elevation component of target velocity, mentally convert it into the required lead angle, and apply it to the sight picture while tracking the target in azimuth.

c. Lead Computer/Lead Compensation - Azimuth and Elevation Axis

The gunner is required to track the target. Lead, in both azimuth and elevation, is automatically inserted by the computer.

d. Burst on Target

To apply the burst on target technique to an airborne target, the gunner must observe the position of the tracer for a preceding round as it passes by the target. He then adjusts the sight picture he had when firing that round by the amount of the miss distance, in the direction that superimposes the round's "impact" position on the target. This process is complicated by the effect of firing shock, which generally causes the gunner's sight picture to be slightly, but significantly, different when the round "impacts" from what it was when the round was fired. Likewise, target motion will complicate the application of the burst on target technique. Use of the burst on target procedure against moving targets is predicated on assumptions that the round and the target will move as they did during the flight of the preceding round. This is a good assumption for the round but may not be very appropriate for the target.

In addition to the variation in gunners' tasks described above, the lead requirements for some rounds are largely independent of target range and for other rounds are substantially influenced by target range. For instance, the average velocity, and therefore lead, of the 105mm and 115mm

APDS rounds are approximately 10 percent different for a 3000 meter range than at the muzzle, whereas the 105mm and 115mm HEAT rounds are between 60 and 75 percent different for a 3000 meter range than at the muzzle.

Since the gunner's tasks listed under a. and b. above include lead compensation, this changing lead requirement with range tends to increase the complexity of his tasks. However, available experimental data indicates that the gunner will not be able to estimate the target velocity to better than 25 percent, rms, and therefore the 10 percent lead increase in the first 3000 meters can be ignored without substantially changing the probability of hitting a target. This, however, is not true for the HEAT rounds; the 60 to 75 percent increase in lead requirements over the first 3000 meters, if ignored, could substantially change the probability of hitting a target.

The ideas expressed in the preceding pages formed the basis for the selection of the M60A1 and its gunner's telescope to be used in TAHOP as the equipment for simulation of the T62 firing APDS (task a). They also form the basis for the selection of the M60A2 as acceptable equipment for testing to determine gunners' capabilities to perform tasks b. and c. (Task d. cannot be evaluated without a live fire test. Live fire, other than a small scale confirmation test for the task a. data is not envisioned as a part of TAHOP or Experiment 43.8.)

The following comments are intended to emphasize the contributions of the basic TAHOP experiment and the proposed expanded version. In addition, the systems and firing doctrines which are not included in either version of TAHOP are identified.

The controlling variables in the following discussion are ammunition characteristics and the gunners' tasks. Because the gunners' tasks are largely determined by the lead related items of fire control hardware and/or firing doctrine, the headings used in the following table refer to the hardware or doctrine. (The definitionsof gunners' tasks are the same as those presented earlier in this paper.)

DEFINITION OF COMBINATIONS FOR SUBSEQUENT DISCUSSION

	AMMUNITION CHARACTERISTICS	
Hardware or Doctrine Key to Tasks	Small Changes in Average Velocity Over First 3000 Meters of Flight (As for APDS Rds)	Medium to Large Changes in Average Velocity over First 3000 Meters of Flight (As for nearly all Non-APDS Rounds)
Simple Sight Ballistic Reticle	a-1	a-2
Lead Computer/Lead Compensation - Azimuth Axis	b-1	b-2
Lead Computer/Lead Compensation - Azimuth and Elevation Axis	c-1	c-2
Burst on Target	d-1	d-2

Each of the combinations defined above will be discussed immediately below.

Combination	Degree to which Combination is Addressed by Either Basic or Expanded TAHOP
a-1	Basic TAHOP will collect data required for good estimates of the capabilities for this combination.
a-2	TAHOP will not address the effect of differences between APDS and other tank fired rounds' average velocity characteristics. Estimates of the capabilities of this combination for gunners who base their lead estimate on a single lead-vs-speed relationship can be made. This would provide a good estimate for a lower bound on the capabilities with this type of ammunition.
b-1	The expanded TAHOP will collect data required for good estimates of the capabilities for this combination. Equipment related effects will relate directly to the M60A2. State-of-the-art, design tolerances, or separately collected test data can be used in preparation of useful estimates for other systems.
b-2	This combination will not be directly addressed in TAHOP. However, horizontal dispersion estimates from combination b-1 (expanded TAHOP) should be adequate for this combination. Vertical dispersion estimates will suffer from the same deficiencies as combination a-2.
c-1, and c-2	These combinations will both be effectively addressed in expanded TAHOP. Again the equipment related effects will relate directly to the M60A2. As in combination b-1, state-of-the-art, design tolerances, or separately collected test data can be used in preparation of useful estimates for other systems.
d-1, and d-2	These combinations will not be addressed in TAHOP. They are not applicable to the APDS round, because it cannot be sensed when fired. They would require live firing of several types of ammunition to infer the relationships between ammunition characteristics, vehicle characteristics, and error magnitudes. Live firings for this purpose are beyond the planned scope of TAHOP.

This concludes the discussion of why TAHOP (both versions) is needed and what is to be gained by conducting this experiment.

Details of the test procedures and instrumentation required are addressed in a separate paper.

EXPANSION OF THE TAHOP EXPERIMENT - INSTRUMENTATION AND TEST PROCEDURES

The purpose of the expanded portion of the TAHOP experiment is to improve the data base available for predicting the capabilities of Soviet or US tanks employing state-of-the-art in fire control equipment, instead of the simple fire control involved in the basic TAHOP experiment.

Instrumentation

The instrumentation for the basic TAHOP is radar for determining target motion, voice channel recorders for recording gunners estimates of range and lead, and cameras for determining the lead, lay, and range accuracy of the gunners' sight pictures. No additional requirements for the radar are imposed by the expansion. Five additional cameras will be required, one for each M60A2 in the test. Likewise, five additional channels on the voice recording equipment will be required, one for each M60A2 in the test.

Additional instrumentation required is

- equipment for recording the lead calculated by the computer in each M60A2 tank,
- equipment for marking the film with the time of lead insertion as well as simulated firing in each M60A2 tank, and
- equipment to automatically remove the applied lead approximately 0.5 sec after it has been inserted in each M60A2 tank.

Test Procedures

The M60A2 tanks will be located in close proximity to the M60A1 tanks. The M60A2 gunners' procedures will differ from the M60A1 gunners' procedures only because of the differences in equipment and related differences

Incl 2

in tasks to be performed. The M60A2 gunners will superimpose the crosshairs of the gunner's periscope on the center of mass of the target, track for at least two seconds, then press the lead insertion button to simulate firing a two axis lead system and initiate calculation of lead by the computer. Following the lead being inserted then removed the gunner will place the vertical crosshair back on the target and place the horizontal crosshair to adjust for vertical lead and simulate firing. At the time the gunner estimates the target's vertical velocity and at the time the gunner converts the velocity to an equivalent lead, these estimates should be spoken to record them on the audio tape. Either the laser rangefinder will be used in this exercise or the correct range will be indexed in the computer and told to the gunner at the start of the run.*

As supplemental data for use in estimating the capabilities of a simple fire control system with a laser rangefinder, the gunners in the M60A2 tanks should record on the voice tapes their estimate of the total apparent crossing velocity. This should be done after the second firing simulation exercise for each target run.

The target runs will not be altered for this portion of the test.

Data reduction requirements will be of the same type as for the basic TAHOP experiment but will be more than double for the film reading portion. However, this portion of the data does not have to be reduced and analyzed prior to the conduct of Experiment 43.8. This area will be developed more fully, later.

Calibration

Calibration requirements for the cameras will be the same as for basic TAHOP. Calibration of the lead measurements will be required.

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* Care must be taken not to let range information be given to the M60A1 gunners.

APPENDIX C - REDUCED DATA TABULATIONS (PART ONE)

C.1 INTRODUCTION

This appendix contains a sample page illustrating reduced data from the basic TAHOP test for a hovering helicopter. The complete tabulation (available upon request) covers the following helicopter maneuver categories:

a. Hover.

b. Constant Speed Level.

c. Constant Speed Non-Level.

d. Nap Of Earth.

e. Other Evasive Targets (Various accelerating paths).

The helicopter maneuver condition is shown as a title on each page and the following additional information is presented for each simulated firing event:

a. Column 1 - Run number, where digit following a space designates a repeat run.

b. Column 2 - Tank number.

c. Column 3 - Gunner number.

d. Column 4 - Range, in meters.

e. Column 5 - Horizontal crossing component of the helicopter speed, in knots.

f. Column 6 - Vertical crossing component of the helicopter speed, in knots.

g. Column 7 - Gunner's estimate of range, in meters.

h. Column 8 - Gunner's estimate of helicopter crossing speed, in knots.

i. Column 9 - Gunner's estimate of lead, in mils.

j. Column 10 - Gunner's range error, in meters.

k. Column 11 - Gunner's lead error, in mils.

l. Column 12 - Lead applied by gunner, in mils, followed after a space by 1 or 0 indicating respectively whether lead was or was not applied in the correct direction.

m. Column 13 - Elevation applied by gunner, in mils.

n. Column 14 - Gunner's horizontal implementation error, in mils.

o. Column 15 - Gunner's vertical implementation error, in mils.

p. Column 16 - Gunner's horizontal error, in mils.

q. Column 17 - Gunner's vertical error, in mils.

C.2 DATA

Explanations covering the meaning of plus and minus signs and the first page of reduced data follow.

HOVER
NUMBER OF CASES = 292

SYMBOL CONVENTIONS

HORIZONTAL SPEED	+ IMPLIES RIGHT-TO-LEFT MOTION
VERTICAL SPEED	+ IMPLIES DOWN-TO-UP MOTION
RANGE ESTIMATE ERROR	+ IMPLIES ESTIMATE LARGER THAN TRUE RANGE
LEAD ESTIMATE ERROR	+ IMPLIES ESTIMATE LARGER THAN LEAD REQUIRED
LEAD APPLIED	+ IMPLIES TARGET RIGHT OF DRIFT LINE IN RETICLE
ELEVATION APPLIED	+ IMPLIES TARGET ABOVE BORESIGHT CROSS
HORIZONTAL IMPLEMENTATION ERROR	+ IMPLIES MORE LEAD APPLIED THAN ESTIMATED
VERTICAL IMPLEMENTATION ERROR	+ IMPLIES TARGET AT GREATER RANGE IN RETICLE THAN ESTIMATED
HORIZONTAL ERROR	+ IMPLIES MORE LEAD APPLIED THAN REQUIRED
VERTICAL ERROR	+ IMPLIES ROUND PASSES ABOVE TARGET

HOVER

1 RUN	2 TANK	3 GUNNER	4 RANGE METERS	5 HOR. SPEED KNOTS	6 VER. SPEED KNOTS	7 RANGE EST. METERS	8 SPEED EST. KNOTS	9 LEAD EST. MILS	10 RANGE ERROR METERS	11 LEAD ERROR MILS	12 LEAD APPLD MILS	13 ELEV. APPLD MILS	14 HOR.IMPL ERROR MILS	15 VER.IMPL ERROR MILS	16 HOR. ERROR MILS	17 VER. ERROR MILS
3 1	2	5	1723	1.48	1.79	1800	0	0	77.	-.5	-.2 0	-2.7	.2	-1.8	-.3	-2.2
3 1	4	1	1718	.82	-.02	1500	0	0	-218.	-.3	-.3 0	-4.3	.3	.5	.0	-.1
3 1	5	7	1718	1.75	1.65	1400	0	0	-318.	-.6	.3 1	-3.8	.3	.3	-.3	-1.1
5 1	1	13	2047	-2.78	1.19	1600	0	0	-447.	-.9	-.1 1	-4.2	.1	.2	-.9	-1.4
5 1	2	5	2049	-3.67	1.61	2300	0	0	251.	-1.2	.2 0	-2.7	.2	-3.2	-1.0	-3.1
5 1	4	1	2053	-1.28	-1.32	2000	0	0	-53.	-.4	.2 0	-4.7	.2	-.4	-.2	-.1
5 1	5	7	2063	-2.31	.99	1800	0	0	-263.	-.8	.0 1	-4.6	.0	.0	-.8	-1.0
13	1	17	1666	-1.03	-.21	1800	0	0	134.	-.3	-7.6 1	-4.2	7.6	-.3	7.3	.1
13	2	5	1659	-2.84	-1.13	1700	0	0	41.	-.9	-1.5 1	-3.4	1.5	-.9	.5	-.4
13	5	11	1644	-2.58	-2.02	1500	0	0	-144.	-.9	-.8 1	-2.9	.8	-.9	-.1	-.6
13	6	14	1650	-2.23	-.35	1500	0	0	-150.	-.7	.4 0	-.3	.4	-3.5	-.3	-3.8
15	1	17	1586	-2.31	.49	1600	0	0	14.	-.8	-1.3 1	-4.1	1.3	.1	.5	-.1
15	2	5	1596	-1.94	-4.78	1500	0	0	-96.	-.6	-1.3 1	-2.9	1.3	-.9	.7	.5
15	3	15	1589	-2.51	1.71	1300	5	0	-289.	-.8	4.1 0	-.9	4.1	-2.4	3.3	-3.7
15	4	1	1594	-2.60	-.41	1400	0	0	-194.	-.9	.0 1	-5.2	.0	1.7	-.9	1.4
15	5	11	1604	-.08	-3.67	1500	0	0	-104.	-.0	-.7 1	-2.8	.7	-.9	.7	.0
21	1	13	1638	-1.32	.54	1300	0	0	-338.	-.4	.3 0	-2.1	.3	-1.2	-.1	-2.2
21	2	9	1633	-1.65	-.91	1500	0	0	-133.	-.6	1.3 0	-3.6	1.3	-.1	.7	-.2
21	3	2	1631	-1.96	-.33	1800	0	0	169.	-.7	.0 0	-2.3	.0	-2.3	-.6	-1.7
21	5	7	1626	-.66	-.51	1600	0	0	-26.	-.2	.4 0	-5.5	.4	1.4	.2	1.5
21	6	14	1624	-1.44	-1.13	1500	0	0	-124.	-.5	-.3 1	.2	.3	-3.9	-.2	-3.9
29	1	13	2138	.78	1.90	1700	0	0	-438.	-.3	.3 1	-2.7	.3	-1.6	.0	-3.4
29	4	16	2142	.60	1.38	1800	0	0	-342.	-.2	.8 1	-7.5	.8	2.9	.6	1.6
29	6	14	2148	.80	1.81	2000	0	0	-148.	-.3	-.8 0	.6	.8	-5.7	.5	-6.7
43	1	17	1557	.66	-7.69	1500	0	0	-57.	-.2	6.6 1	.6	6.6	-4.4	6.4	-1.9
43	2	5	1558	.51	-3.19	1500	0	0	-58.	-.2	.4 1	-2.8	.4	-1.0	.3	-.1
43	3		*******						ESTIMATE	DATA	MISSING					*******
43	5	11	1577	-3.94	-6.74	1600	0	0	23.	-1.3	-2.4 1	-3.2	2.4	-.8	1.1	1.5
55	1	13	2169	-.23	-1.32	2200	0	0	31.	-.1	.3 0	-4.3	.3	-1.3	.2	-.8
55	2	9	2168	1.75	.72	2000	0	0	-168.	-.6	-.3 0	-5.6	.3	.5	-.2	-.1
55	3	2	2159	-.14	-1.59	2100	0	0	-59.	-.0	-.2 1	-3.2	.2	-2.2	.1	-1.8
55	5	7	2163	.39	-.62	1900	0	0	-263.	-.1	.3 1	-4.5	.3	-.3	.1	-.8
55	6	14	2149	-1.53	.00	1500	0	0	-649.	-.5	2.3 0	.1	2.3	-3.8	1.8	-5.6
78	1	13	2602	.84	-2.39	2000	0	0	-602.	-.3	.2 1	-5.3	.2	.2	-.0	-.6
78	3	2	2605	5.25	-.52	2500	0	0	-105.	-1.7	.8 1	-3.3	.8	-3.1	-.9	-3.2
78	5	7	2614	.43	-.41	2800	0	0	187.	-.1	.2 1	-8.3	.2	1.1	.1	1.7
79	2	9	2137	.66	-.51	2000	0	0	-137.	-.2	1.2 1	-5.1	1.2	.1	1.0	-.1
79	3	2	2135	2.14	-.89	2300	0	0	165.	-.7	-.0 0	-2.9	.0	-3.0	-.7	-2.3
79	5	7	2132	4.22	-1.85	2000	0	0	-132.	-1.4	-.0 0	-5.2	.0	.1	-1.4	.4
82	1	13	2087	-1.40	-.93	2300	0	0	213.	-.5	1.4 0	-5.5	1.4	-.4	.9	.5
82	2	9	2070	.93	-1.13	2000	0	0	-70.	-.3	-.2 0	-4.6	.2	-.5	-.1	-.3
82	3	2	2064	-1.03	2.68	2400	0	0	337.	-.3	-.0 1	-2.4	.0	-3.7	-.3	-3.7
82	5	7	2056	-1.55	2.49	2200	0	0	144.	-.5	.3 0	-5.8	.3	.2	-.3	-.2
94	1	13	2595	-3.67	-.82	2500	5	2	-95.	.8	13.8 0	-5.2	11.8	-1.2	12.6	-1.2
94	2	9	2597	-2.66	2.08	2000	0	0	-597.	-.9	-.1 1	-5.6	.1	.5	-.8	-1.7
94	3	2	2593	-2.43	1.48	2300	0	0	-293.	-.8	-.6 1	-2.9	.6	-3.0	-.2	-4.3
94	4	1	2592	-2.45	1.07	1500	0	0	-1092.	-.8	.8 0	-4.0	.8	.2	-.0	-3.0
94	6	14	2587	-2.66	.91	2000	0	0	-587.	-.9	-.4 1	-.1	.4	-5.0	-.5	-6.8
100 1	2	5	2489	-2.51	2.78	2800	0	0	311.	-.8	.2 0	-2.6	.2	-4.6	-.7	-4.7
100 1	4	1	2491	1.65	.21	2000	0	0	-491.	-.6	.1 1	-4.6	.1	-.5	-.5	-1.9

APPENDIX D - REDUCED DATA TABULATIONS (PART TWO)

D.1 INTRODUCTION

This appendix contains a sample page illustrating additional reduced data for the same firing events as the sample page in Appendix C. The complete data tabulation (available upon request) identifies the helicopter maneuver condition as a title on each page and gives the following additional information for each firing event:

a. Column 1 - Run number, as for Appendix C.

b. Column 2 - Tank number, as for Appendix C.

c. Column 3 - Gunner number, as for Appendix C.

d. Column 18 - Trial start time, in hours, minutes, and seconds.

e. Column 19 - Film fire time, in hours, minutes, and seconds.

f. Column 20 - Radar fire time, in hours, minutes, and seconds.

g. Column 21 - Target azimuth angle, in degrees.

h. Column 22 - Target elevation angle, in degrees.

i. Column 23 - Target approach angle, in degrees.

j. Column 24 - Total target speed (magnitude of the combination of the three component speeds), in knots.

k. Column 25 - Target closing speed, in knots.

D.2 DATA

The first page of the data tabulation follows.

HOVER

1 RUN	2 TANK	3 GUNNER	18 TRIAL START TIME H M S	19 FILM FIRE TIME H M S	20 RADAR FIRE TIME H M S	21 TARGET AZIMUTH ANGLE DEG	22 TARGET ELEVATION ANGLE DEG	23 TARGET APPROACH ANGLE DEG	24 TOTAL TARGET SPEED KNOTS	25 TARGET CLOSING SPEED KNOTS
3 1	2	5	12 57 32	12 57 43	12 57 45	-150.9	5.6	103.5	2.3	0.3
3 1	4	1	12 57 32	12 57 35	12 57 36	-151.3	5.4	148.4	1.6	1.3
3 1	5	7	12 57 32	12 57 46	12 57 46	-152.2	5.8	100.6	2.4	0.3
5 1	1	13	12 39 41	12 39 55	12 39 55	175.6	2.0	74.8	3.1	-0.8
5 1	2	5	12 39 41	12 39 57	12 39 58	175.6	2.1	113.4	4.3	1.6
5 1	4	1	12 39 41	12 39 45	12 39 46	174.6	2.0	132.2	2.2	1.2
5 1	5	7	12 39 41	12 39 48	12 39 48	174.2	2.1	138.9	3.6	2.6
13	1	17	9 55 47	9 56 4	9 56 5	-148.3	2.6	109.0	1.1	0.3
13	2	5	9 55 47	9 56 9	9 56 10	-148.4	2.6	54.3	3.7	-2.0
13	5	11	9 55 47	9 55 50	9 55 51	-150.2	2.8	51.9	3.9	-2.0
13	6	14	9 55 47	9 56 3	9 56 3	-150.3	2.7	121.0	2.6	1.3
15	1	17	10 2 33	10 2 43	10 2 44	-177.9	2.8	109.5	2.5	0.8
15	2	5	10 2 33	10 3 0	10 3 0	-177.3	2.7	42.7	5.6	-2.1
15	3	15	10 2 33	10 2 46	10 2 47	-178.4	2.9	102.9	3.1	0.6
15	4	1	10 2 33	10 2 46	10 2 46	-178.7	2.9	96.4	2.7	0.3
15	5	11	10 2 33	10 2 37	10 2 38	-179.6	2.8	2.1	4.3	-2.2
21	1	13	10 26 21	10 26 42	10 26 43	-149.4	2.3	124.8	1.7	0.9
21	2	5	10 26 21	10 26 31	10 26 31	-150.0	2.4	97.1	1.9	0.2
21	3	2	10 26 21	10 26 29	10 26 29	-150.3	2.4	123.4	2.4	1.3
21	5	7	10 26 21	10 26 35	10 26 36	-151.2	2.4	42.8	1.1	-0.7
21	6	14	10 26 21	10 26 32	10 26 32	-151.7	2.4	81.7	1.8	-0.2
29	1	13	10 53 15	10 53 32	10 53 32	-174.1	1.9	103.9	2.1	0.2
29	4	16	10 53 15	10 53 46	10 53 46	-174.7	1.9	32.1	1.8	-1.0
29	6	14	10 53 15	10 53 32	10 53 32	-175.6	1.9	67.4	2.0	-0.3
43	1	17	13 53 1	13 53 12	13 53 13	-177.8	2.4	101.2	7.7	0.1
43	2	5	13 53 1	13 53 20	13 53 20	-178.2	2.8	38.1	3.3	-0.6
43	3		*******			ESTIMATE DATA	MISSING			*******
43	5	11	13 53 1	0 0 0	0 0 0	-179.4	3.0	51.0	8.4	-3.2
55	1	13	15 2 54	15 3 12	15 3 12	-141.7	2.1	156.7	1.4	0.5
55	2	5	15 2 54	15 3 16	15 3 16	-141.9	2.1	154.9	4.2	3.7
55	3	2	15 2 54	15 3 3	15 3 4	-142.2	2.3	177.1	3.2	2.8
55	5	7	15 2 54	15 3 24	15 3 25	-142.9	2.3	159.1	1.3	1.0
55	6	14	15 2 54	15 3 9	15 3 9	-143.2	2.2	50.7	2.0	-1.3
78	1	13	17 16 60	17 10 24	17 10 24	-164.6	2.4	88.4	2.5	-0.0
78	3	2	17 16 60	17 17 9	17 17 10	-165.3	2.4	115.8	5.8	2.5
78	5	7	17 16 60	17 17 16	17 17 17	-166.1	2.3	121.6	0.6	0.3
79	2	5	17 19 24	17 19 35	17 19 35	-154.5	3.1	21.3	1.9	-1.7
79	3	2	17 19 24	17 19 37	17 19 37	-154.8	3.2	71.2	2.4	-0.7
79	5	7	17 19 24	17 19 41	17 19 41	-155.8	3.1	97.1	4.6	0.5
82	1	13	17 28 33	17 21 50	17 21 50	-142.5	3.0	28.8	3.1	-2.5
82	2	5	17 28 33	17 28 47	17 28 47	-143.0	2.7	56.8	1.6	-0.6
82	3	2	17 28 33	17 28 51	17 28 51	-143.1	2.8	25.9	3.6	-2.1
82	5	7	17 28 33	17 28 50	17 28 50	-143.9	2.9	34.3	3.7	-2.3
94	1	13	9 37 43	9 38 1	9 38 1	-147.2	2.9	61.5	4.3	-2.0
94	2	5	9 37 43	9 37 53	9 37 55	-147.6	2.8	59.1	3.7	-1.6
94	3	2	9 37 43	9 37 57	9 37 57	-147.7	2.9	59.9	3.2	-1.4
94	4	1	9 37 43	9 37 58	9 37 58	-147.9	2.9	58.6	3.1	-1.5
94	6	14	9 37 43	9 37 51	9 37 52	-148.7	2.8	60.6	3.2	-1.5
100 1	2	5	12 26 57	12 27 17	12 27 19	150.7	2.6	80.7	3.8	-0.4
100 1	4	1	12 26 57	12 27 0	12 27 1	150.2	2.6	134.8	2.3	1.7

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